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Sewage Sludge Pathogen Transport Model Project

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16. ABSTRACT

The sewage sludge pathogen transport model predicts the number of Salmonella, Ascaris, and polioviruses which might be expected to occur at various points in the environment along 13 defined pathways. These pathways describe the use of dried or liquid, raw or anaerobically digested sludge as a cropland fertilizer, dried raw sludge as an animal feed supplement, and composted sludge as a residential soil amendment.

The model uses a compartment-vector approach in which a mathematical state represents a discrete point in a treatment or application pathway where pathogen populations are computed as a function of time. Within these compartments, mathematical process functions describe population changes due to environmental factors. Pathogen exchanges between compartments are described by transfer functions. The model permits user specification of various parameters in both process and transfer functions, enabling him to simulate a unique set of environmental conditions.

Five separate exposure risk calculations provide risk assessment determinations for pathogens associated with airborne particulates, residue and soil, vegetable crops, meat, and milk. Certain of the exposure risk calculations can be modified by the model user to simulate unique exposure conditions. The model can be progressively modified to accommodate new information, thus constantly enhancing its predictive accuracy.

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by

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Health Effects Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

This report describes a computer model which follows sewage sludge pathogens through common treatment alternatives and into the environment after the sludge is beneficially used. The model is designed to aid in sludge management by providing a means for comparing the risks of different treatment and application regimes.

James B. Lucas, M.D.
Acting Director
Health Effects Research Laboratory

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ABSTRACT

The sewage sludge pathogen transport model predicts the numbers of salmonella, ascaris, and polioviruses which might be expected to occur at various points in the environment along 13 defined pathways. These pathways describe the use of dried or liquid, raw or anaerobically digested sludge as a cropland fertilizer, dried raw sludge as an animal feed supplement, and composted sludge as a residential soil amendment.

The model uses a compartment-vector approach in which a mathematical state represents a discrete point in a treatment or application pathway where pathogen populations are computed as a function of time. Within these compartments, mathematical process functions describe population changes due to environmental factors. Pathogen exchanges between compartments are described by transfer functions. The model permits user specification of various parameters in both process and transfer functions, enabling him to simulate a unique set of environmental conditions. The model has the additional capability of performing exposure risk calculations for environmental compartments specified by the model user at the time of model variable initialization. The calculations are then performed automatically at each hour interval using the pathogen population calculated for the compartment at that time.

Five separate exposure risk calculations provide risk assessment determinations for pathogens associated with airborne particulates, residue and soil, vegetable crops, meat, and milk. Certain of the exposure risk calculations can be modified by the model user to simulate unique exposure conditions. The model can be progressively modified to accommodate new information, thus constantly enhancing its predictive accuracy.

This report, BDM/TAC-79-528-TR, summarizes the work that was performed on the Pathogen Risk Analysis Program. This activity was performed under Sandia Laboratories Contract 13-8410 and Interagency Agreement 78-D-X0116 with the U.S. Department of Energy, Albuquerque, New Mexico. Appendix B of this document is a user's guide and programmer/analyst's guide for the Library Storage and Retrieval Programs developed during this effort.

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ABBREVIATIONS AND SYMBOLS

D_{10} = Dose of radiation that is required to reduce a populations of pathogens to 10 percent of its original number.

E = FORTRAN symbol denoting exponentiation, 2.4E6 = 2.4×10^6.

N(i) = Number of pathogens in the specified compartment at a specified time.

ρ = rho = Greek letter used to denote process functions which define alterations in pathogen populations within compartments.

τ = tau = Greek letter used to denote transfer functions which define the movement of pathogen populations between compartments.

* = FORTRAN symbol denoting multiplication, 2. * 2. = 4.

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The BDM Corporation wishes to acknowledge the contributions of J. S. Sivinski and R. L. Ward of Sandia National Laboratories, Division 4535. They saw the need for a comprehensive evaluation of the risks to human health from pathogens in municipal sludge used for beneficial purposes. Their advocacy helped see the project through to a successful conclusion.

We also wish to acknowledge the guidance and support of the U.S. Environmental Protection Agency project officers Dr. N. E. Kowal (Health Effects Research Laboratory) and Gerald Stern (Municipal Environmental Research Laboratory) who provided guidance throughout the project.

The following BDM professionals participated in the successful completion of this project: J. F. Dawson, K. E. Hain, B. McClure, R. E. Sheridan, and J. G. Yeager.

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SECTION 1

INTRODUCTION

The constraints imposed on sewage treatment and disposal by clean air and water legislation are increasing the amounts of sewage sludge which a municipality must dispose of while reducing disposal alternatives. Legislation has encouraged waste management procedures which emphasize the recycling and beneficial use of waste materials. At the same time, the consequences of such use are being questioned. Before municipal officials can consider using sludge for beneficial purposes they must decide whether the environmental release of human pathogens inherent in sewage sludge poses an unacceptable risk.

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One mission of the Applied Biology and Isotope Utilization Division of Sandia Laboratories is the development of cost-beneficial uses for existing and future supplies of radioactive isotopes. The Waste Resources Utilization Program, a major subprogram of the Beneficial Uses Program, has developed methods, using cesium-137, to reduce the pathogen content of municipal sewage sludge so that the organic and nutrient value of sludge can be used safely and productively. As a result of this effort, a prototype sewage sludge irradiator has been developed which may make this treatment technology available to municipalities.

The extent of the health hazard posed by enteric pathogens in sludge, however, remains an unanswered question. In an attempt to evaluate and possibly quantify this hazard, Sandia Laboratories contracted with The BDM Corporation to accumulate an information base that would include available relevant data regarding pathogen occurrence in sewage, pathogen survival during common sewage treatment processes, and pathogen movement through the environment as a result of sludge application and use. A computerized library storage and retrieval system was designed to classify and store the abstracts of reviewed literature which constitute the information base. This information base was used to develop a computer model which predicts the numbers of specific pathogens that would be found in sewage sludge at various points during sludge treatment and application. Once the pathogen population estimates are determined for points in the environment, the model has the added capability of assessing the risk to health resulting from human exposure to the pathogens. The model is a first step towards evaluating the potential risk to human health from beneficial uses of municipal sewage sludge.

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SECTION 2

CONCLUSIONS

A computer model has been developed to describe the alterations in sewage sludge pathogens during sludge treatment processes and following the application of sludge to beneficial purposes in agriculture. The health risk assessment capability incorporated into the model will allow individuals involved in sludge management decisions to make informal judgements about the relative health risks of various sludge use options.

The accuracy of this or any other predictive model is directly related to the quality of the quantitative data that are used in the development of the mathematical relationships in the model. Data are available on most aspects of microbial survival during sewage treatment processes. However, most of these data are qualitative in nature and cannot be used directly in the development of quantitative mathematical relationships. Quantitative data available for bacteria are often concerned with the fate of indicator organisms. It was often necessary to extrapolate these data to the less numerous and usually more fastidious pathogenic bacteria. The validity of this extrapolation is subject to the similarities between the pathogens and indicators. Data concerning enteric parasites are usually qualitative in nature, and problems exist in assessing the viability of resistant forms. There is much recent data concerning the survival of viruses during sewage treatment. Most of this information pertains to poliovirus and may not be applicable to other viral pathogens, especially hepatitis A and rotavirus.

Much of the current information on the persistence of pathogens in the environment is also qualitative in nature. Most of the data from laboratory studies lacks confirmation under field conditions. Conversely, descriptive field studies generally do not include laboratory investigation of underlying basic principles. The lack of quantitative information on the relative contributions of interacting environmental parameters such as pH, temperature, microbial antagonism, moisture, toxic substances, ultraviolet radiation, etc. makes it impossible to model the discrete microprocesses that affect environmental survival of pathogens.

The Sewage Sludge Pathogen Transport Model uses general mathematical descriptions of pathogen behavior during treatment and in the environment. The modular structure of the model allows the easy incorporation of any desired microprocess data as it becomes available. The mathematical relationships in the model were developed using data from three representative pathogens, salmonella, ascaris, and poliovirus. If this caveat is kept in mind, the model can be modified by an informed user to predict the survival and health risks associated with other pathogens.

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The risk assessment portion of the model was developed in the absence of information concerning the probability of exposure of individuals to pathogens originating from sludge. Because these data are not available, the risk assessment portion of the model assumes that an individual is exposed to sludge pathogens. The model then provides the user with information about the conditions of exposure that would lead to infection or disease.

As developed, the model will be a useful tool for exploring the relative health risks associated with a variety of user-defined sludge treatment and application scenarios. The value of the model will be its ability to provide rapid comparisons of relative health risks rather than its ability to accurately quantify pathogen survival in the environment.

The Sewage Sludge Pathogen Transport Model was developed on the CDC (Control Data Corporation) 6600 computer at Sandia National Laboratories in Albuquerque, New Mexico. The transportability of the model's FORTRAN code may be limited by characteristics of this computer and its operating system and by the use of several unique system programs in the model.

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The Library Storage and Retrieval Programs developed as part of this project are a flexible framework that can be modified for the collection and selective retrieval of information on other topics. The existing system can provide a nucleus for a continually expanding collection of information on the fate of various pathogens during sludge treatment and after application to the environment.

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SECTION 3

RECOMMENDATIONS

The Sewage Sludge Pathogen Transport Model is a first attempt at evaluating the risk to human health from the pathogens in sewage sludge used for beneficial purposes. Extensive testing and validation should precede use of the model as input to sludge-management decisions.

The accuracy of the model's population estimates would be enhanced if data from comprehensive, integrated studies were available. There is a need for coordinated, thorough laboratory and field studies of pathogen behavior during sewage treatment and after introduction to the environment. Experiments that discriminate between the relative contributions of various environmental stresses on pathogen survival would enable microprocess modeling rather than the macroprocess approach used in the development of this model.

The model will be most effectively used as a tool for comparing the human health risk associated with a wide variety of user-tailored sludge treatment and use scenarios. The population estimates provided by the model are derived from experimental data where available. However, the previously mentioned shortcomings in the data make it clear that the model's strength is in providing comparisons rather than accurate pathogen population estimates.

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SECTION 4

SCOPE OF PROJECT

The sludge treatment and application alternatives described in the computer model were specified by Sandia Laboratories. These alternatives include the use of cesium-137 gamma irradiation in conjunction with the following sludge uses:

a. Dried raw sludge applied to cropland as a fertilizer.

b. Dried, anaerobically digested sludge applied to cropland as a fertilizer.

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c. Dried raw sludge used as a feed supplement for ruminant animals.

d. Composted sludge used as a soil conditioner by the general public.

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e. Liquid raw or anaerobically digested sludge applied to cropland as a fertilizer.

In designing the computer model, these treatments and applications were divided into 13 separate pathways which describe the major steps in the flow of pathogens through the environment.

Four pathways were developed which describe sludge treatments. Pathway 1, General Sludge Treatment Pathway, describes the treatment of raw or digested sludge for application as cropland fertilizer. Pathway 2, Sludge Treatment Pathway - Animal Feed Supplement, describes the treatment of raw sludge necessary to prepare an animal feed supplement. Pathway 3, Sludge Treatment Pathway - Composting of Raw or Digested Sludge, describes a general composting cycle to render sludge an inoffensive residential soil amendment. Pathway 10, Sludge Treatment Pathway - Liquid Sludge, describes the treatment of either raw or anaerobically digested, liquid sludge intended for application to cropland.

Nine pathways describe the applications of sludge that could follow the defined treatment alternatives. Pathway 4, Sludge Application Pathway - Fertilizer for Crops Destined for Human Consumption, and Pathway 11, Sludge Application Pathway - Liquid Sludge Used as a Fertilizer for Crops Destined for Human Consumption, describe the environmental flow of pathogens after sludge is applied to cultivated farm land producing common vegetable crops. Pathway 5, Sludge Application Pathway - Fertilizer for Pasture Crops, and Pathway 12, Sludge Application Pathway - Liquid Sludge

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Used as Fertilizer for a Grazed Pasture, describe the use of treated sludge on a grazed field, while Pathway 6, Sludge Application Pathway - Fertilizer for Crops That Are Processed Prior to Animal Consumption, and Pathway 13, Sludge Application Pathway - Liquid Sludge Used as Fertilizer on Crops That Are Processed Prior to Animal Consumption, describe the use of treated sludge on field crops harvested for animal consumption. Pathway 7, Sludge Application Pathway - Animal Feed Supplement, is designed to evaluate the use of herbivore feeds containing sludge such as those prepared in Pathway 2. Pathways 8 and 9, Sludge Application Pathway - Residential Garden Soil Amendment and Sludge Application Pathway - Residential Lawn Soil Amendment, respectively, describe the application of composted sludge to home vegetable gardens and in the establishment of a new lawn. Diagrams of each of the 13 pathways are shown in Figures 1 through 13 (each located with the corresponding pathway description). Complete descriptions of the pathways are located in Section 5.

Considering modern disposal practices, any pathogenic organism can be found in municipal sewage. It would be difficult to design a model which could accurately simulate the survival and environmental movement of more than a few specific organisms. Three organisms were selected to represent the enteric pathogens most commonly found in sludge. These organisms were chosen because each causes significant disease in the general population; there was more information available concerning these organisms than for other members of the principal pathogen groups; and each is exceptionally hardy, surviving longer than average outside the human body. *Salmonella* species were used to represent the bacteria; *Ascaris* species were used to represent parasites, both the helminths and the protozoa; and polioviruses were used to represent all enteric viruses. No representative for the fungi was selected because not enough information is available on this group as a whole or on any individual member of the group to support the type of decision making which is the foundation of environmental modeling.

The possible growth, inactivation, and movement of each of the three selected pathogens, salmonella, ascaris, and poliovirus, were analyzed for each compartment and transfer of the 13 defined pathways which constitute the sewage sludge pathogen transport model. The model uses the state-vector approach. A state or compartment is a discrete point along a pathway where the pathogen population is computed as a function of time. Compartments are indicated in the pathway illustrations as boxes labeled to indicate what processes are acting on the pathogen populations. Within each compartment, first-order, linear, differential equations are derived to compute the rate and direction of change in the pathogen population and the effect that any subprocesses in a compartment may have on that population. The process functions which describe population changes are vectors including parameters to account for time, temperature, moisture content, nutrients, etc. The transfer of pathogens between compartments is described by a set of ordinary differential equations derived using conservation principles, environmental parameters, and relationships developed from data obtained in the literature review. These equations are then integrated to determine the pathogen populations in each compartment.

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The state-vector approach used to develop the sewage sludge pathogen transport model provides a structure with the capability for supporting both stochastic and deterministic mathematical relationships. It provides a flexibility of model structure which permits addition and/or deletion of pathway compartments and modifications in process and transfer functions. The modeling effort itself has served as a tool to identify areas where data is currently nonexistent or incomplete and where further research is needed. Informed estimates were incorporated into the model in these less studied areas. As new information becomes available these estimates can be removed from the model and can be replaced with supported data. The model can be progressively modified, thus constantly enhancing its predictive accuracy.

Each of the selected pathogens differs in its response to treatment and environmental processes. Process and transfer functions were developed to describe each pathogen population separately. The user selects which pathogen will be considered in any particular pathway run. The user may also control the environmental conditions to be simulated in the model by inputting user-selected variables to define duration of compartments, temperature, rainfall, and other parameters. Default values for each parameter are incorporated into the model. These values are based on the extensive literature review which preceded the modeling effort. The decisions which resulted in variable value determinations are documented in the report. The user may compare the final pathogen populations of one pathogen against another for a particular pathway, or of one pathogen against itself for several different pathways, or may compare the effects of different parameter values on pathogen populations within and between pathways. For example, the default value for ambient temperature in all 13 pathways is 20°C. It is possible to follow all three pathogens through a particular pathway in separate runs. Then specify an ambient temperature of 30°C and follow the pathogens through again. Then compare the six print-outs.

The model pathways were developed using relationships that describe the behavior of representatives of three pathogen classes (bacterial, viral, parasitic) during sewage treatment and in the environment following their dissemination in sludge. The flexible structure of the model and the ample supply of user-specifiable variables will allow an informed user to adapt compartments in any of the pathways to describe the fate of other members of each pathogen class. It must be remembered, however, that even pathogens in the same class may differ widely in their responses to stresses encountered during treatment or in the environment. For example, one might incorporate data describing Mycobacterium tuberculosis into the process function associated with one of the compartments in a pathway. The model will function normally with these data incorporated, but it must be remembered when interpreting model output that the relationships in the other comparments of the pathway describe the behavior of salmonella. These changes can be made according to the instructions in Appendix A to this document

In addition to the 13 sludge treatment and application pathways just described, the model contains five exposure risk calculations. These

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calculations provide estimates of the risk to human health resulting from exposure to sludge pathogens associated with airborne particulates, soil or residue, vegetable crops, meat, and milk. These calculations are executed automatically when the model user elects to determine the risk associated with the environmental compartment to which the exposure risk calculations are coupled. The exposure risk calculations begin with the number of pathogens present in the selected compartment (e.g., RESIDUE). The pathogen population is then modified based on a series of events that would normally occur during a human exposure. The final pathogen number is compared with human-dose-response data to provide an estimate of the circumstances that would lead to a human infection. For example, the model would provide the number of vegetable units that would have to be consumed to provide an infectious dose. Certain aspects of these calculations may be modified at the time of model initialization by the model user to enable him to tailor the exposure scenario according to unique conditions. A detailed explanation of the model's risk assessment capabilities and their use can be found in Section 6 of this report.

The information base upon which the Sewage Sludge Pathogen Transport Model is based was the result of an extensive literature search. Over 1000 titles have been identified, read, and abstracted. Each abstract was classified using a set of selected keywords and was entered into a computerized data base using the Library Storage and Retrieval Programs designed during this project. A complete description of the storage and retrieval programs can be found in Appendix B of this report. Some of the articles which constitute the information base were identified through the use of automated literature searches of established data bases including BIOSIS (Biology Abstracts and Bioresearch Index), AGRICOLA (National Agriculture Catalog), COMPEDEX (Engineering Index), WRA (Water Resources Abstracts), POLLUTION (Pollution Abstracts) and MEDLINE (Medical Research Literature). Others were suggested in bibliographies kindly supplied by experts in various specific fields. In addition to published data, the knowledge and experience of many professionals were sought through interviews and through visits to sewage treatment facilities (of Albuquerque, New Mexico, and of the County Sanitation Districts of Los Angeles, California), to a feed mill, and to farming operations, as well as through conversations during professional meetings and seminars.

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SECTION 5

DESCRIPTION OF TREATMENT AND APPLICATION PATHWAYS

The sewage sludge pathogen transport model provides estimates of pathogen flow through the environment as a result of the sewage sludge treatment and application alternatives specified by Sandia Laboratories. These alternatives include the use of cesium-137 gamma irradiation in conjunction with the following sludge uses:

a. Dried raw sludge applied to cropland as a fertilizer.

b. Dried anaerobically digested sludge applied to cropland as a fertilizer.

c. Dried raw sludge used as a feed supplement for ruminant animals.

d. Composted sludge used as a soil conditioner by the general public.

e. Liquid raw or anaerobically digested sludge applied to cropland as a fertilizer.

For computer model design purposes, the sludge treatment and sludge product application portions of the five alternatives listed above were defined in 13 separate environmental pathways (see table on next page).

Sludge treatment and application pathways are described in detail below. Briefly, a series of mathematical states or compartments define places in the environment where pathogen levels (denoted by $N(i)$) are to be estimated. These are represented by boxes in the pathway diagrams (Figures 1-13). Mathematical expressions termed "process functions" (denoted by rho, ρ) describe the fate of pathogens within each of these compartments. The flow of pathogens between compartments is described by mathematical expressions called "transfer functions" (denoted by tau, τ). In the pathway diagrams, a compartment enclosed by a dashed line is optional and may or may not be selected for inclusion in the pathway. This selection is made by the model user when the pathways are defined for a given "run" of the model. In some of the pathways, pathogens are transferred to environmental locations that have not been mathematically defined as compartments. These locations are not boxed by either dashed or solid lines in pathway diagrams. The transfers to these locations represent the removal of pathogens from the environmental pathway and from further consideration by the model. The mass-balance approach used in the model requires that these transfers of pathogens be defined even though no

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attempt is made to predict alterations in these populations subsequent to their transfer.

PATHWAY TYPES

Treatment Pathways

1. General Sludge Treatment
2. Animal Feed Supplement
3. Composting Raw or Digested Sludge

10. Liquid Sludge

Application Pathways

4. Fertilizer for Crops Destined for Human Consumption
5. Fertilizer for Pasture Crops
6. Fertilizer for Crops That Are Processed Prior to Animal Consumption
7. Animal Feed Supplement
8. Residential Garden Soil Amendment
9. Residential Lawn Soil Amendment
11. Liquid Sludge Used as a Fertilizer for Crops Destined for Human Consumption
12. Liquid Sludge Used as a Fertilizer for a Grazed Pasture
13. Liquid Sludge Used as a Fertilizer on Crops That Are Processed Prior to Animal Consumption

To provide a high degree of flexibility in the computer model, many of the key parameters associated with the transfer of pathogens and with the effects of processes on pathogen population levels have been designated as variables. These variables may be changed without modification to the basic computer code. Thus, the model user is able to tailor conditions for a given model run to emphasize certain environmental factors that he may want to examine. If the model user does not wish to specify variable values, he may use the default values that are programmed into the model.

The linear differential equation solver, ODE, is the routine used to solve the system of differential equations which are the model. These equations are composed of the process and transfer functions which are calculated for each compartment. The RHOs (process functions) have either a growth function, death function, or no-activity function associated with them. No activity is simply setting that particular process function to zero, which adds nothing to the respective differential equation in regards to increase or decrease in populations.

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The data used for determining the process functions were obtained from the scientific literature. The process functions were determined from the data using the standard expression for exponential growth or death of microorganisms.

$$N_t = N_0 \cdot e^{mt}$$

where N_t = pathogen population at time t
N_0 = original pathogen population at t = 0
e = base of the natural logarithms
m = inactivation or growth rate constant
t = elapsed time for t = 0

For example, if the literature yields a three-order-of-magnitude reduction in pathogens over a 24-hour period because of some environmental stress (e.g., elevated temperature), the process function is calculated using the following values in this expression.

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$N_0 = 1$

$N_t = 0.001$

t = 24 hours

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Then: $N_t = 1*N_0 = N_0*e^{m*0}$ at t = 0 (1)

and $N_t = 0.001*N_0 = N_0*e^{m*24}$ at t = 24 (2)

Dividing equation 2 by equation 1 to solve for m,

$$0.001 = e^{24*m}$$

and

$$m = \frac{\ln (0.001)}{24} = -0.2878$$

Thus, for each hour that this particular process function applies, the value supplied to the differential equation solver, ODE, for calculating the updated population at each hour interval is RHO = -0.2878*N (where N is the pathogen population at the end of the previous integration increment).

The first pathway of each type - treatment or application - is described in detail. Thereafter, the pathway descriptions are briefer, containing information pertinent to the pathway under discussion but avoiding repetition of basic modeling concepts such as diagram symbols, use of variables, and the calculation of particulates.

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PATHWAY 1 - GENERAL SLUDGE TREATMENT PATHWAY

General Considerations

This pathway describes the fate of sewage sludge pathogens during the treatment processes involved in the generation of dried, raw, or anaerobically digested sludge to be used as fertilizer. Figure 1 shows the process compartments and transfers which define this treatment option. The differential equations which describe this pathway, reflecting the relationships expressed in Figure 1 and forming the basis of the computer program, are presented in Table 1a. Each process function (ρ_i) and transfer function (τ_i) is defined in the following section, where each compartment is described in detail.

Process functions are designated by RHO followed by the compartment number, so that RHO1 would designate the change in pathogen population occurring in Compartment 1. The Greek symbol "ρ" with a subscript to indicate the appropriate compartment number is used in equations. Transfer functions are designated by TAU followed by the number of the compartment from which the transfer is made and then the number of the compartment into which the transfer is going. TAU32 designates the transfer from Compartment 3 into Compartment 2. The Greek symbol "τ" with a subscript is used in equations and in the pathway diagrams (Figures 1-13) to indicate defined transfers. TA followed by the appropriate compartment numbers is substituted for TAU when more than three digits are needed to define a transfer. This shortening is necessitated by program language limits. Labeled arrows are used in pathway diagrams to help identify the direction of flow between model compartments. Each compartment is descriptively named to indicate the sort of process being modeled by the corresponding computer subprogram. In pathway diagrams, the compartment number usually appears on the upper right hand corner of the box representing the compartment.

Table 1b lists both the definitions of and default values for the input variables used to define environmental factors which affect process and transfer functions. The model user may supply a value for any input variable and, thus, set the program to model a specific situation of concern. Table 1b also lists output variables generated by the computer program. These variables are not available to the user as input but are often used in pathway descriptions to define time increments and pathogen levels. The general considerations and assumptions discussed below were made to facilitate model development.

a. The pathway considers the total, 1-day sludge production of a 30-million gallon per day (MGD)* sewage treatment plant. Only those processes concerned with the generation and processing of sewage sludge are considered. The following assumptions were made concerning the character of the raw sewage entering the treatment plant (84).**

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* The conventional MGD unit is used throughout this report. One MGD equals 0.0438 m^3/s.

** Numbers in parenthesis located throughout the text refer to the refrences listed at the back of this document.

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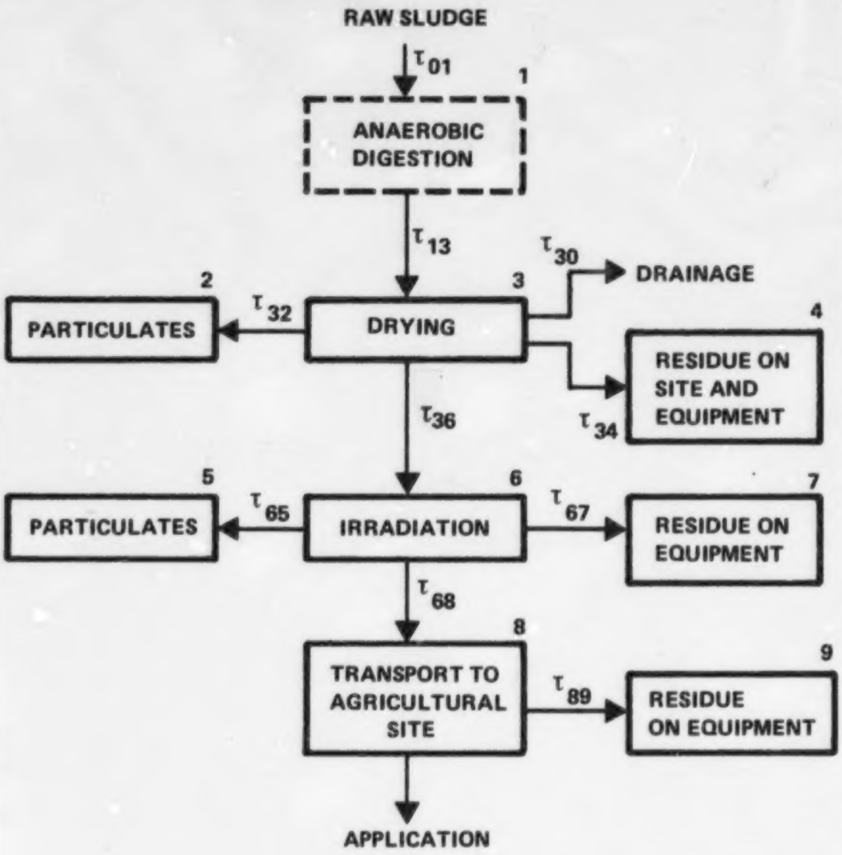
RAW SLUDGE
τ_{01}
1
ANAEROBIC DIGESTION
τ_{13}
τ_{30}
DRAINAGE
2
PARTICULATES
τ_{32}
3
DRYING
4
RESIDUE ON SITE AND EQUIPMENT
τ_{34}
τ_{36}
5
PARTICULATES
τ_{65}
6
IRRADIATION
τ_{67}
7
RESIDUE ON EQUIPMENT
τ_{68}
8
TRANSPORT TO AGRICULTURAL SITE
τ_{89}
9
RESIDUE ON EQUIPMENT
APPLICATION

Figure 1. General Sludge Treatment Pathway

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TABLE 1a. DIFFERENTIAL EQUATIONS FOR PATHWAY 1
GENERAL SLUDGE TREATMENT PATHWAY

$$\dot{N}_1 = \tau_{01} - \tau_{13} + \rho_1$$

$$\dot{N}_2 = \tau_{32} + \rho_2$$

$$\dot{N}_3 = \tau_{13} - \tau_{30} - \tau_{32} - \tau_{34} - \tau_{36} + \rho_3$$

$$\dot{N}_4 = \tau_{34} + \rho_4$$

$$\dot{N}_5 = \tau_{65} + \rho_5$$

$$\dot{N}_6 = \tau_{36} - \tau_{65} - \tau_{67} - \tau_{68} + \rho_6$$

$$\dot{N}_7 = \tau_{67} + \rho_7$$

$$\dot{N}_8 = \tau_{68} - \tau_{89} + \rho_8$$

$$\dot{N}_9 = \tau_{89} + \rho_9$$

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TABLE 1b. VARIABLES FOR PATHWAY 1
GENERAL SLUDGE TREATMENT PATHWAY

POSITION	DEFAULT VALUE	VARIABLE	DEFINITION
		INPUT VARIABLES	
1	1.3057E+7 4.5698E+2 5.2226E+7	ASCRS	Number of pathogens per kilogram of dry solids after primary sedimentation.
2	1.5318E+4	PLCAP	Plant capacity in kilograms of dry solids per day.
3	PLCAP*ASCRS	ASCIN	Number of pathogens per day entering pathway. If present, overrides first two variables.
4	1.	ANAER	Selects Anaerobic Digestion Compartment if set = 1.0; does not select if set = -1.0.
5	720.	ANTIM	If Anaerobic Digestion Compartment is selected, then this sets the duration of the compartment (in hours).
6	70.	PRSOL	Percent solids desired at the end of the Drying Compartment.
7	20.	TEMP	Ambient temperature throughout pathway in degrees Celsius.
8	0.18382	WTPAR2	Weight in kilograms of particulates generated in Compartment 2.
9	10.	WTRES4	Dry weight in kilograms of sludge transferred to Residue in Compartment 4.
10	150. 150. 1000.	DOSE	Radiation dosage in kilorads from irradiator.
11	1.5318E-2	WTPAR5	Weight in kilograms of particulates generated in Compartment 5.

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TABLE 1b. (concluded)

POSITION	DEFAULT VALUE	VARIABLE	DEFINITION
12	5.	WTRES7	Dry weight in kilograms of sludge transferred to Residue in Compartment 7.
13	168.	STIME4	Duration in hours of Compartment 8, Transport to Agricultural Site.
14	0.00005	FRLOSS	Fraction of pathogens inactivated each hour during Transport to Agricultural Site.
15	5.	WTRES9	Dry weight in kilograms of sludge transferred to Residue in Compartment 9.
		OUTPUT VARIABLES	
16	(output)	STIME5	Time at completion of Compartment 8.
17	(output)	STIME1	Time at completion of Compartment 1.
18	(output)	STIME2	Time at completion of Compartment 3.
19	(output)	STIME3	Time at completion of Compartment 6.
20	(output)	PTOTL	Pathogens/kilogram at the end of the pathway.

NOTES: The number of pathogens per day entering the pathway will default to PLCAP*ASCRS if no value is specified for ASCIN. If a value is specified for ASCIN, it will override the PLCAP*ASCRS value.

Whenever three default values are specified for any variable in the list above, the order is salmonellae, ascaris, poliovirus pathogen types. The appropriate default value will be selected to agree with the pathogen type being considered in a particular run.

All units of measure are in kilograms, degrees Celsius, or hours unless otherwise stated.

Variables labeled "output" are for internal computations and are not available to the user as input.

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1. Total solids concentration of the raw sewage is 225 mg/l. This represents a total plant capacity of 25,531 kilograms of dry solids per day.

2. Primary sedimentation is 60 percent efficient in the removal of suspended solids. Hence, 15,318 kilograms of dry solids are present in the raw sludge entering the pathway. This represents 306 cubic meters of liquid sludge with a solids concentration of 5 percent.

b. The number of pathogens entering the pathway each day in the 30 million gallons of raw sewage is a model-user-supplied value that may be based on personal experience. The user may supply either the total number of pathogens entering the pathway (variable ASCIN in Table 1b) or both the number of pathogens per kilogram of sludge (ASCRS) and the amount of raw sludge being considered (PLCAP). The default values that have been provided within the computer program represent "average" pathogen levels in municipal sewage (1, 4, 28, 32, 77), but user-supplied values based on local experience will provide the most useful model output. The user must select one pathogen type for each model run.

c. The anaerobic digestion process is optional, as is indicated by the dashed lines surrounding this compartment in Figure 1. If raw, undigested sludge is being modeled, this process is bypassed and the entering pathogen population is transferred directly to the next pathway process, which is drying. The model assumes a batch mesophilic anaerobic digestion process. Duration of digestion is a user-supplied value which defaults to 30 days.

d. The raw or anaerobically digested sludge produced by the sewage treatment plant is dried by a combination of evaporation and gravity drainage. It is assumed that the total sludge volume is contained in a 30-centimeter-deep sludge-drying bed. The gravity removal of liquid from the sludge occurs over a 2-day period and results in a 20 percent solids sludge. This sludge then evaporates at a rate equal to 70 percent of the clear water evaporation rate for the Albuquerque area (10, 84). The final solids concentration at the end of the drying process is specified by the model user, and this solids concentration remains constant throughout the rest of the pathway. The time required for the drying process depends, therefore, on the final solids concentration chosen by the model user. The model provides a default final solids concentration of 70 percent. The time required to achieve this level of dryness is 35 days. During the drying process, pathogen populations are affected by ambient temperature and sludge solids concentration.

e. After drying, sludge-associated pathogens are subjected to a user-specified dose of gamma irradiation. Default dosages provided in the model will give a three-log reduction in the total

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number of pathogens. The time required for the irradiation process depends on the dose desired and the amount of sludge to be processed. The time required to deliver the selected irradiation dose is based on the design of the Sandia Laboratories' Irradiator for Dried Sewage Solids, a prototype irradiator that can deliver a 1-megarad dose to 8 tons of sludge in 1 day (61).

f. The time required for transporting the dried irradiated sludge to the site of application is a user-specified value. This value also allows the model user to specify the length of time that the sludge will be stored prior to its use. The model provides a default of 7 days for the duration of this compartment.

g. The amount of airborne particulates generated during various parts of this pathway is derived from the United States Department of Labor Occupational Health and Safety Administration's limit for the amount of total inert airborne particulates allowed in industrial processes (82). A particulate concentration of 15 milligrams per cubic meter of air is generated in a 10-meter-high volume above work areas considered in appropriate compartments in the pathway. For example, the sludge drying bed is defined with an area of 1,255 square meters. The 10-meter-high volume above the bed would be 12,550 cubic meters. A concentration of 15 milligrams of particulates per cubic meter would give 183 grams of airborne particulates. The particulates are generated at the beginning of a given compartment process time, and the particulate-associated pathogen populations are unaltered for the duration of the compartment activities which generate the particulates. This provides for a constant presence of the maximum level of particulate-associated pathogens to which a worker would be exposed.

h. The ambient temperature during the pathway is provided by the model user and remains constant throughout the pathway. A default temperature of 20°C is provided.

i. The transfer of pathogens with residue, at various locations, is computed by dividing the weight of the residue left by the total weight of sludge present in the transferring compartment and then multiplying this fraction by the number of pathogens present. For example, 20 kilograms transferred to residue from the drying compartment would represent 0.13 percent (20 kilograms/15,318 kilograms) of the sludge in the drying compartment. Hence, 0.13 percent of the pathogens will be transferred along with the 20 kilograms of sludge. The defaults provided in the model are estimates only, and a fraction of transfer based on user experience would enhance the pathogen estimates in this and similar cases.

j. The total pathway duration is variable and depends on the model-user-selected values for the time of anaerobic digestion, the

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desired solids content after drying, the total dose of irradiation to be delivered, and the time selected for transportation and storage of the treated sludge.

Compartment Descriptions

Compartment 1, ANAEROBIC DIGESTION --

This treatment process is optional. The process functions of Compartment 1 will be activated only if the variable ANAER is set equal to one. This is the default condition. If any other value is assigned to the variable, the pathogen population will be transferred unaltered to Compartment 2. When ANAER = 1, the variable ANTIM which specifies the digestion time must be set to at least 24 hours because pathogens are transferred into the compartment over a 24-hour period.

Significant Calculations - Review of the literature showed that populations of salmonella and poliovirus are reduced by approximately two and three orders of magnitude, respectively, during anerobic digestion. This reduction is reported regardless of the duration of the digestion period. Apparently, most of the reduction occurs over a relatively short period early in digestion and then the rate of reduction levels off. To simulate the net effect of anaerobic digestion, the process function RHO1 has been set to allow for a uniform reduction in population over the duration of digestion (ANTIM). If the anaerbic digestion time is less than 3.2 (for poliovirus) or 4.4 (for salmonella) the reduction in population occurs at the most rapid rate over the selected period of digestion. Because ascaris ova are not affected by anaerobic digestion, no change in ascaris occurs in this compartment.

The inactivation rate of pathogens during longer periods of anaerobic digestion is calculated by the model based on the pathogen type and the time selected for ANAEROBIC DIGESTION.

The equation describing the number of pathogen present at any point in time in Compartment 1 is:

$$N_t = N_0 e^{mt} \quad (1)$$

where
N_t = the number of pathogens present at the beginning of the time increment under consideration.
N_0 = number of pathogens at the beginning of the anaerabic digestion process.
e = base of natural logarithm
t = elapsed time
m = inactivation rate constant

At a time 24 hours ($t = 24$) after the start of the pathway, all of the pathogens will have been transferred into the compartment and

$$N_{24} = N_0 e^{(m*24)} \quad (2)$$

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For salmonella, where a two-log reduction occurs over the period of anaerobic digestion, the number present at the end of anaerobic digestion is given by

$$N_{ANTIM} = N_{24}\ (10^{-2}) = N_0 e^{(m*ANTIM)} \qquad (3)$$

Dividing equation 2 by equation 3 gives

$$10^2 = e^{m(24-ANTIM)} \qquad (4)$$

Thus,

$$m = [-\ln\ (10^2)/(ANTIM - 24)]$$

For this salmonella population undergoing anaerobic digestion, RHO1 = m*N where N is the population at the beginning of the time increment being considered.

For poliovirus, the calculation is the same except that a three-log reduction is used.

Time of first transfer into compartment - Start of pathway.

Time of last transfer out of compartment - ANTIM.

Process function - RHO1
    Activated: Start of pathway.
    Duration: Until ANTIM
    Rates: Salmonella: -0.044*N(1)/hour, when ANTIM ≤ 4.4 days. (57, 77)
        (-ln (10.E2.)/ANTIM-24.))*N(1)/hour, when ANTIM > 4.4 days
    Ascaris: -0.00041*N(1)/hour. (22, 31, 32, 70)
    Poliovirus: -0.09*N(1)/hour, when ANTIM ≤ 3.2 days. (2, 59, 86)
        (-ln (10.E3.)/ANTIM-24.))*N(1)/hour, when ANTIM > 3.2 days

Transfers into compartment -
    TAU01 = ASCIN, Transfer occurs at the start of the pathway.

Transfers out of compartment -
    TAU13 = N(1), Transfer occurs at ANTIM.

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*Numbers in parenthesis located at the end of a rate statement refer to the references used as sources of parameter values.

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Compartment 2, PARTICULATES --

Particulates, to a level of 15 mg/m^3, are generated at the end of DRYING into the volume above the sludge drying bed. The bed is assumed to be 1255 square meters in size to accommodate a day's production of sludge in a 30-centimeter deep layer. Particulate-associated pathogens are unaffected by process functions for 1 hour after particulate generation. The delay in process function activation permits risk assessment of maximum exposures during the time required for workers to remove sludge from the drying bed.

Time of first transfer into compartment - STIME2.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RHO2
    Activated: STIME2 + 1 hour.
    Duration: Until all pathogens are depleted or the end of the pathway.
    Rates: Salmonella: -0.46*N(2)/hour. (8)
        Inactivation of particulate-associated salmonella is assumed to occur at the same rate as in drying sludge at greater than 80 percent solids.
    Ascaris: -0.25*N(2)/hour. (22, 40, 74)
    Poliovirus: -0.3838*N(2)/hour. (88, 97)

Transfers into compartment -
    TAU32 = (WTPAR2/PLCAP)*N(3), Transfer occurs at STIME2.

Transfers out of compartment - None.

Compartment 3, DRYING --

If ANAEROBIC DIGESTION is bypassed, the initial pathogen population input to the pathway will enter DRYING at the start of the pathway. If the sludge is digested, the pathogen population transfers into this compartment at ANTIM. The time required for DRYING is calculated from the solids concentration desired at the end (a value specified by the variable PRSOL) and the time required to achieve this solids concentration assuming sludge dries at 0.7 times the clear water evaporation rate (10, 84) after removal of free water by gravity drainage. The default solids concentration of 70 percent requires a drying time of 35 days. Drying time is calculated by the computer program and added to the digestion time (ANTIM) to yield the output variable STIME2, the time at completion of this compartment.

Transfers are made from DRYING into Compartment 2 (TAU32), Compartment 6 (TAU36), Compartment 4 (TAU34), and to DRAINAGE (TAU30). Pathogens are removed from sludge with the effluent which drains away through the underdrain system of the drying bed during the first 48 hours of DRYING. Drainage is recirculated to the primary sedimentation basin within the treatment

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plant and is not considered as a compartment within the model. The fraction of total sludge pathogens transferred to DRAINAGE is an estimate.

The three transfers from the DRYING compartment into other compartments are all made at the end of drying, time STIME2. A weight of sludge and the pathogens associated with that sludge are transferred into Compartment 2, PARTICULATES, by TAU32. This simulates the generation of dust during removal of dried sludge from the drying beds. Another amount of sludge and the pathogens associated with it are left in the bed and cling to removal equipment. This is the weight of sludge transferred into Compartment 4, RESIDUE ON SITE AND EQUIPMENT, by TAU34. The remaining sludge and pathogens are transferred into Compartment 6, which represents the next treatment process, IRRADIATION. This transfer is accomplished by TAU36.

Significant Calculations - The percent solids concentration of the drying sludge is calculated dynamically as a linear function using an initial value of 5 percent solids for wet sludge and the user-specified value of PRSOL as the end point.

Time of drying in days =

$$\frac{83.25 - (100 - (\%\ \text{solids} - 5.))}{1.35}\ ,\ \text{when } 20 < \%\ \text{solids} < 100.$$

$$\frac{95.0 - (100 - (\%\ \text{solids} - 5.))}{7.25}\ ,\ \text{when } 5 \leq \%\ \text{solids} \leq 20.$$

Time of first transfer into compartment - Start of pathway or ANTIM depending upon the value assigned to ANAER.

Time of last transfer out of compartment - STIME2.

Process function - RHO3
Activated: At ANTIM.
Duration: Until STIME2.
Rates: Salmonella: 0.13*N(3)/hour, for % solids of sludge ≤ 70 and 20 ≤ TEMP ≤ 40 to an upper limit of 1x10^9 per kilogram solids. This growth rate is 1/2 the rate of E.coli in sterile sludge. (76)
-0.05*N(3)/hour, for 70 < % solids < 80 and TEMP < 40. (8)
-3.45*N(3)/hour, for % solids < 80 and TEMP ≥ 40. (8, 93)
-0.46*N(3)/hour, for % solids ≥ 80. (8)
0.0*N(3)/hour, for % solids < 80 and TEMP ≤ 20.
Ascaris: -0.0012*N(3)/hour, for TEMP < 40 and % solids < 80. (40)
-1.535*N(3)/hour, for TEMP ≥ 40 and % solids < 80. (7, 78)

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-0.25*N(3)/hour, for TEMP < 40 and % solids > 80. (22, 40, 77)

Poliovirus: -0.01*N(3)/hour, for % solids < 65 and TEMP <45. (44, 87)
-0.38*N(3)/hour, for TEMP ≥ 45. (88, 97)
-0.02*N(3)/hour, for % solids ≥ 65 and TEMP < 45. (87)

Transfers into compartment -
TAU13 = N(1), Transfer occurs at ANTIM.

Transfers out of compartment -
TAU30 salmonella = 0.1*N(3)
TAU30 ascaris = 0.01*N(3)
TAU30 poliovirus = 0.05*N(3)
} Transfers occur over a 48-hour period beginning at ANTIM.

TAU32 = (WTPAR2/PLCAP)*N(3), Transfer occurs at STIME2.
TAU34 = (WTRES4/PLCAP)*N(3), Transfer occurs at STIME2.
TAU36 = N(3) - (TAU30 + TAU32 + TAU34), Transfer occurs at STIME2.

Compartment 4, RESIDUE ON SITE AND EQUIPMENT --

Not all sludge will be removed from the drying bed at the end of DRYING. Some fraction and the fraction of the pathogen population associated with it will remain. Sludge will also adhere to removal equipment. The variable which estimates the weight of sludge left as residue, WTRES4, is a user-specifiable value. The calculation involved in determining the pathogen content of residue is done by the subroutine for Compartment 3 since the number of pathogens to be transferred must be known before the transfer takes place.

Time of first transfer into compartment - STIME2.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RHO4
Activated: STIME2 + 1 hour.
Duration: Until all pathogens are depleted or the pathway ends.
Rates: Salmonella: -0.46*N(4)/hour. (8)
The inactivation of salmonella in residue is assumed to occur at the rate for salmonella in drying sludge at greater than 80 percent solids.
Ascaris: -0.25*N(4)/hour. (22, 40, 74)
Poliovirus: -0.384*N(4)/hour. (88, 97)

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Transfers into compartment -
TAU34 = (WTRES4/PLCAP)*N(3), Transfer occurs at STIME2.

Transfers out of compartment - None.

Compartment 5, PARTICULATES --

Particulates are generated from the sludge being loaded into the irradiator. A 10-meter high volume above a 126-square-meter loading pad is filled with 15 milligrams per cubic meter of pathogen carrying particules. As in other PARTICULATE compartments, the process function is not activated at generation but is delayed until the generating activity, in this case, irradiation, is completed. This allows maximum exposure of sewage plant personnel to aerosols. The calculations which determine the number of pathogens entering this compartment are made in the subroutine for Compartment 6.

Time of first transfer into compartment - STIME2.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RHO5

Activated:	STIME3 + 1 hour.		
Duration:	Until all pathogens are depleted or the pathway ends.		
Rates:	Salmonella:	-0.46*N(5)/hour.	(8)
	Ascaris:	-0.25*N(5)/hour.	(22, 40, 74)
	Poliovirus:	-0.38*N(5)/hour.	(88, 97)

Transfers into compartment -
TAU65 = (WTPAR5/PLCAP)*N(6), Transfer occurs at STIME2.

Transfers out of compartment - None.

Compartment 6, IRRADIATION --

This compartment describes the change in pathogen populations when sludge is subjected to gamma irradiation with cesium-137. The radiation dose to be delivered to the sludge is a variable (DOSE). The time required to deliver the selected dose to the sludge is calculated by the model using the processing capacity of the Sandia Irradiator for Dried Sewage Solids which can deliver a 1,000 kilorad (krd) dose to 8 tons (7272 kg) in a 24-hour period. The relationship between delivered dose and processing capacity is inversely proportional (i.e., at the lower dose of 500 krd, 16 tons (14,544 kg) can be processed per day). For example, if 20,000 kg of sludge is to be given a radiation dose of 150 krd, 0.4125 days, as is shown in the equation, would be required to process the sludge.

$$20000 \text{ kg} \div \left(\frac{1000 \text{ krd}}{150 \text{ krd}} \cdot 7272 \frac{\text{kg}}{\text{day}}\right) = 0.4125 \text{ days}$$

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Responses of pathogens to irradiation, as interpreted in process function rates, assume that a fraction or multiple of the D_{10} value dose will result in the corresponding fraction or multiple pathogen reduction. The D_{10} value for salmonella is 54 krd. Therefore, a dose of 135 krd would result in a 2.5 order-of-magnitude reduction in the salmonella population. Once the total level of pathogen reduction has been determined as just described, the model distributes the reduction evenly over the time specified for sludge processing. The D_{10} values used in the model are: salmonella - 54 krd (8, 94), ascaris - 50 krd (7, 9), and poliovirus - 150 krd (85).

Two components are included in the process functions for this compartment. RHO6(1) models the effects of irradiation while RHO6(2) models the effects of heat and dryness.

Sludge and associated pathogens are transferred from the IRRADIATION compartment to Compartment 5, PARTICULATES, by TAU65; Compartment 7, RESIDUE ON EQUIPMENT, by TAU67; and Compartment 8, TRANSPORT TO AGRICULTURAL SITE, by TAU68. PARTICULATES, simulated by the transfer of an amount of sludge to Compartment 5, are generated by the loading of sludge into the irradiator. The concentration of particulates and the level of associated pathogens above the loading pad stay constant during the entire irradiation period. At STIME3, when all the sludge has been processed, the process functions for PARTICULATES are activated. At this time the transfer from IRRADIATION to Compartment 7 is also made. This transfer represents a residue of sludge left on the irradiator. The bulk of the sludge is transferred to Compartment 8. The compartment represents both the transport and storage of sludge after irradiation.

Significant calculations - RHO6(1), the process function describing inactivation of pathogens by gamma radiation, is determined using the following considerations:

The first transfer into the compartment occurs at STIME2, and the last transfer out of the compartment occurs at STIME3, which is the sum of STIME2 and the irradiation processing time calculated as described above. During this period, a pathogen population is reduced by a factor of $10^{(DOSE/D_{10})}$.

The equation describing the number of pathogens present at any given time during the irradiation process is:

$$N = N_0 e^{mt} \tag{1}$$

where N = number of pathogens present at the beginning of the time increment under consideration

N_0 = number of pathogens at the beginning of the irradiation process

e = base of natural logarithms

t = elapsed time

m = inactivation rate constant

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Then at STIME2,

$$N_{STIME2} = N_0 e^{(m + STIME2)} \qquad (2)$$

and at STIME3,

$$N_{STIME3} = N_{STIME2} \, 10^{(-DOSE/D_{10})} \qquad (3)$$

Dividing equation (2) by equation (3) gives

$$10^{(DOSE/D_{10})} = e^{(m(STIME2 - STIME3))}$$

Thus, (4)

$$m = [(-\ln(10^{(DOSE/D_{10})}))/(STIME3 - STIME2)]$$

For this population undergoing irradiation RHO6(1) = m*N where N is the population at the beginning of the time increment being considered.

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Time of first transfer into compartment - STIME2.

Time of last transfer out of compartment - STIME3.

Process functions - RHO6
Activated: STIME2.
Duration: Until STIME3.
Rates: RHO6 = RHO6(1) + RHO6(2)
Salmonella: RHO6(1) = ((-ln(10.E(DOSE/54.))) (STIME3 - STIME2))*N(6)/hour. (8, 94)
RHO6(2) = -0.05*N(6)/hour, for TEMP < 40 and PRSOL < 80. (8)
= -3.45*N(6)/hour, for TEMP > 40 and PRSOL < 80. (8, 93)
= -0.46*N(6)/hour, for PRSOL > 80 and any temperature. (8)
Ascaris: RHO6(1) = ((-ln (10.E(DOSE/50.)))/(STIME3 - STIME2))*N(6)/hour. (7, 9)
RHO6(2) = 0.0*N(6)/hour, for TEMP < 40 and PRSOL < 95. (7, 9, 38)
= -1.5*N(6)/hour, for TEMP > 40 and PRSOL < 95. (7, 78)
= -0.25*N(6)/hour, for PRSOL > 95 and any temperature. (22, 40, 74)
Poliovirus: RHO6(1) = ((-ln (10.E(DOSE/150.)))/(STIME3 - STIME2))*N(6)/hour. (85)

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RHO6(2) = -0.38*N(6)/hour, for TEMP ≥ 45. (88, 97)
= -0.01*N(6)/hour, for TEMP < 45. (87)

Transfers into compartment -
TAU36 = N(3) - (TAU30 + TAU32 + TAU34), Transfer occurs at STIME2.

Transfers out of compartment -
TAU65 = (WTPARS/PLCAP)*N(6), Transfer occurs at STIME2.
TAU67 = (WTRES7/PLCAP)*N(6), Transfer occurs at STIME3.
TAU68 = N(6) - (TAU65 + TAU67), Transfer occurs at STIME3.

Compartment 7, RESIDUE ON EQUIPMENT --

Some sludge and associated pathogens are assumed to remain on the irradiation equipment after the treated sludge has been removed from the area. The user may supply the weight of sludge left behind by specifying a value for variable WTRES7. The calculation to determine the fraction of input pathogens associated with this weight of sludge is completed before the transfer into this compartment from Compartment 6.

Time of first transfer into compartment - STIME3.

Time of last transfer out of the compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RHO7
Activated: STIME3.
Duration: Until all pathogens are depleted or the pathway ends.
Rates: Salmonella: -0.46*N(7)/hour. (8)
Ascaris: -0.25*N(7)/hour. (22, 40, 74)
Poliovirus: -0.38*N(7)/hour. (88, 97)

Transfers into compartment -
TAU67 = (WTRES7/PLCAP)*N(6), Transfer occurs at STIME3.

Transfers out of compartment - None.

Compartment 8, TRANSPORT TO AGRICULTURAL SITE --

After sludge is irradiated it must be delivered to the site where it will be used. It is possible that the sludge will be stored either near the treatment plant or near the agricultural site before being utilized. This compartment provides the process functions for stored sludge. Sludge in transit is, in effect, stored since the factors affecting pathogen survival are temperature and dryness in both cases. The user may specify the duration of the activities in this compartment by assigning a value to STIME4.

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A weight of sludge and associated pathogens are transferred to Compartment 9 by TAU89 at STIME5. STIME5 equals STIME3, the time at completion of Compartment 6, plus STIME4, the duration of Compartment 8. This transfer simulates a residue left in a storage facility and on equipment when sludge is utilized at an agricultural site.

Time of first transfer into compartment - STIME3.

Time of last transfer out of compartment - STIME5.

Process function - RHO8
  Activated: STIME3.
  Duration: STIME4.
  Rates:
    Salmonella:
      $0.13 * N(8)$/hour, for $PRSOL \leq 70$ and $20 < TEMP < 45$. There is an upper limit placed on growth of 1×10^9 salmonella per kilogram dry solids. The growth of salmonella in sludge at less than 80 percent solids is an estimate based upon one-half the growth rate of E.coli in sterile sludge (76).
      $-0.05 * N(8)$/hour, for $70 < PRSOL < 80$ and $TEMP < 45$. (8)
      $-3.45 * N(8)$/hour, for $PRSOL < 80$ and $TEMP \geq 45$. (8, 93)
      $-0.46 * N(8)$/hour, for $PRSOL \geq 80$ and any temperature. (8)
      $0.0 * N(8)$/hour, for $PRSOL < 80$ and $TEMP \leq 20$.
    Ascaris:
      $0.0 * N(8)$/hour, for $PRSOL < 95$ and $TEMP < 40$. (7, 9, 38)
      $-1.535 * N(8)$/hour, for $PRSOL < 95$ and $40 \leq TEMP < 50$. (7, 78)
      $-0.25 * N(8)$/hour, for $PRSOL \geq 65$ and $TEMP < 45$. (17, 40, 74)
    Poliovirus:
      $-0.01 * N(8)$/hour, for $PRSOL < 65$ and $TEMP < 45$. (44, 87)
      $-0.38 * N(8)$/hour, for $TEMP \geq 45$ and any PRSOL. (88, 97)
      $-0.02 * N(8)$/hour, for $PRSOL \geq 65$ and $TEMP < 45$. (87)

Transfers into compartment -
  TAU68 = N(6) - (TAU65 + TAU67), Transfer occurs at STIME3.

Transfers out of compartment -
  TAU89 = (WTRES9/PLCAP)*N(8), Transfer occurs at STIME5.

Compartment 9, RESIDUE ON EQUIPMENT --
Sludge and associated pathogens are transferred into this compartment at STIME5 when the sludge is utilized. The pathway will continue for 24 hours after this transfer is made. This allows the process functions of

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the compartment to be scrutinized. The fraction of the total remaining pathogens which are associated with the weight of sludge transferred is calculated in the subprogram for Compartment 8.

Time of first transfer into compartment - STIME5.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RHO9
  Activated: STIME5.
  Duration: Until all pathogens are depleted or the pathway ends.
  Rates: Salmonella: -0.46*N(9)/hour. (8)
    Ascaris: -0.25*N(9)/hour. (22, 40, 74)
    Poliovirus: -0.38*N(9)/hour. (88, 97)

Transfers into compartment -
  TAU89 = (WTRES9/PLCAP)*N(8), Transfer occurs at STIME5.

Transfers out of compartment - None.

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PATHWAY 2 - SLUDGE TREATMENT PATHWAY - ANIMAL FEED SUPPLEMENT

General Considerations

This pathway describes the fate of sewage sludge pathogens during the treatment processes involved in the manufacture of an animal feed supplement from dried raw sludge. Figure 2 shows the process compartments and transfers which define this treatment regime. The differential equations which describe this pathway are presented in Table 2a. Each process function and transfer function is defined in the following section. Table 2b lists the definitions of and default values for the input variables used to define environmental factors. The general considerations and assumptions discussed below were made to facilitate model development.

a. As in Pathway 1, this pathway considers the total 1-day production of a 30 million gallon per day (MGD) sewage treatment plant. Primary Sedimentation is included in this pathway but not in Pathway 1 or 3. A 2-hour retention time is assumed for this process. The model user may specify treatment plant capacity in kilograms of dry solids (PLCAP) and the number of pathogens per kilogram of dry solids (ASCRS) or the total number of pathogens being considered per day (ASCIN). Default values given for ASCRS are industry averages (1, 28, 31, 77). The user must select one type of pathogen - salmonella, ascaris, or poliovirus - for each model run.

b. The raw sludge produced is dried by a combination of evaporation and gravity drainage. It is assumed that the total sludge volume is contained in a 30-centimeter-deep sludge-drying bed. The gravity removal of liquid from the sludge occurs over a 2-day period and results in a sludge that is 20 percent solids. The sludge then evaporates at a rate equal to 70 percent of the clear water evaporation rate for the Albuquerque area (10, 84). The final solids concentration at the end of the drying process is specified by the model user; this solids concentration remains constant throughout the rest of the pathway. The time required for the drying process depends, therefore, upon the final solids concentration chosen by the model user. The model provides a default final solids concentration of 70 percent. The time required to achieve this level of dryness is 35 days. During the drying process, pathogen populations are affected by ambient temperature and sludge solids concentration.

c. After drying, sludge-associated pathogens are subjected to a user-specified dose of gamma irradiation. Default radiation dosages provided in the model will give a three-log reduction in the total number of pathogens. The time required for the irradiation process depends upon the dose desired and the amount of sludge to be processed. The time required to deliver the selected irradiation dose is based upon the design of the Sandia Laboratories' Irradiator for Dried Sewage Solids, a prototype

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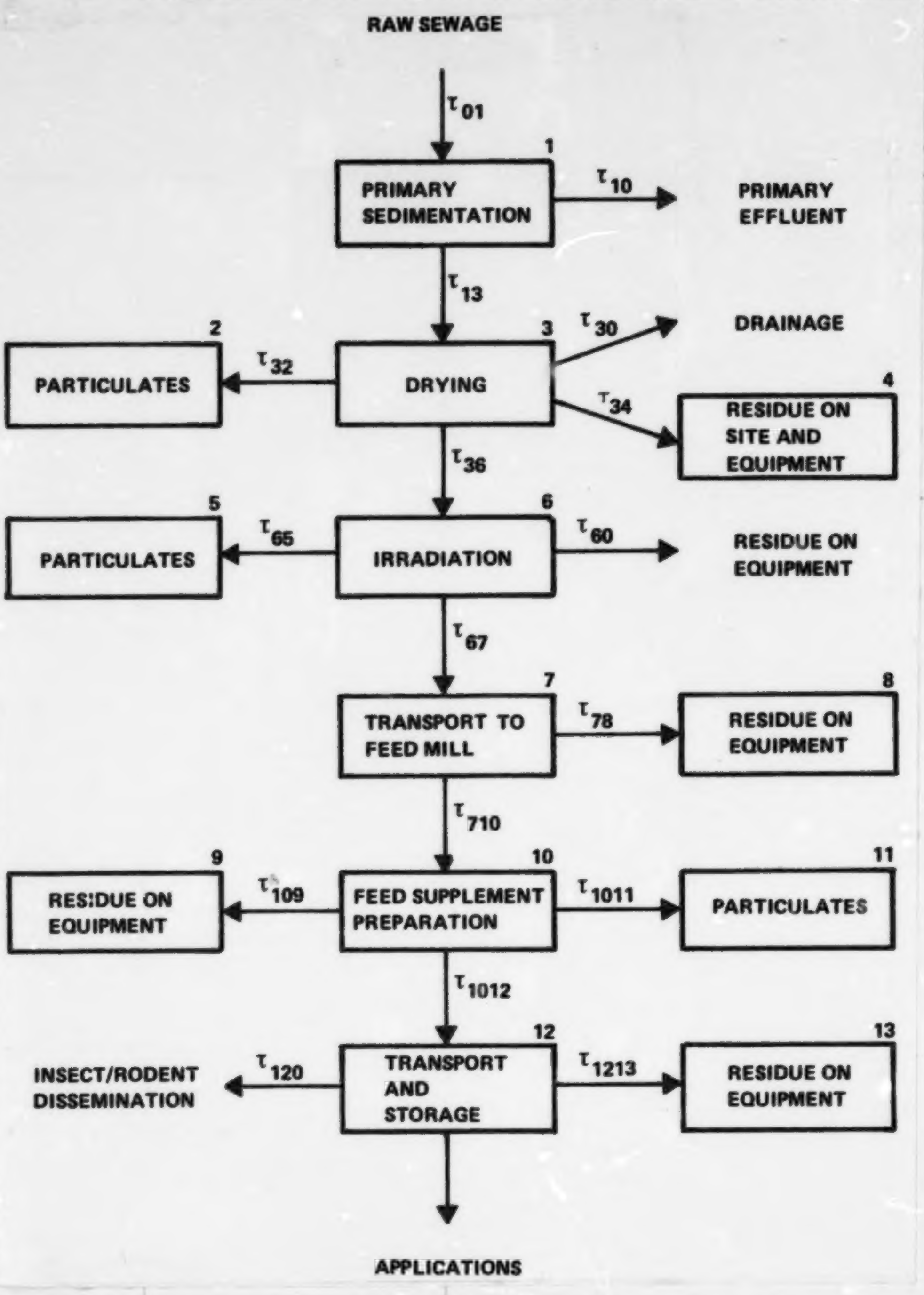
RAW SEWAGE
τ_{01}
1
PRIMARY SEDIMENTATION
τ_{10}
PRIMARY EFFLUENT
τ_{13}
2
PARTICULATES
τ_{32}
3
DRYING
τ_{30}
DRAINAGE
τ_{34}
4
RESIDUE ON SITE AND EQUIPMENT
τ_{36}
5
PARTICULATES
τ_{65}
6
IRRADIATION
τ_{60}
RESIDUE ON EQUIPMENT
τ_{67}
7
TRANSPORT TO FEED MILL
τ_{78}
8
RESIDUE ON EQUIPMENT
τ_{710}
9
RESIDUE ON EQUIPMENT
τ_{109}
10
FEED SUPPLEMENT PREPARATION
τ_{1011}
11
PARTICULATES
τ_{1012}
INSECT/RODENT DISSEMINATION
τ_{120}
12
TRANSPORT AND STORAGE
τ_{1213}
13
RESIDUE ON EQUIPMENT
APPLICATIONS

Figure 2. Sludge Treatment Pathway - Animal Feed Supplement

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TABLE 2a. DIFFERENTIAL EQUATIONS FOR PATHWAY 2
SLUDGE TREATMENT PATHWAY - ANIMAL FEED SUPPLEMENT

$$\dot{N}_1 = \tau_{01} - \tau_{10} - \tau_{13} + \rho_1$$

$$\dot{N}_2 = \tau_{32} + \rho_2$$

$$\dot{N}_3 = \tau_{13} - \tau_{30} - \tau_{32} - \tau_{34} - \tau_{36} + \rho_3$$

$$\dot{N}_4 = \tau_{34} + \rho_4$$

$$\dot{N}_5 = \tau_{65} + \rho_5$$

$$\dot{N}_6 = \tau_{36} - \tau_{60} - \tau_{65} - \tau_{67} + \rho_6$$

$$\dot{N}_7 = \tau_{67} - \tau_{78} - \tau_{710} + \rho_7$$

$$\dot{N}_8 = \tau_{78} + \rho_8$$

$$\dot{N}_9 = \tau_{109} + \rho_9$$

$$\dot{N}_{10} = \tau_{710} - \tau_{109} - \tau_{1011} - \tau_{1012} + \rho_{10}$$

$$\dot{N}_{11} = \tau_{1011} + \rho_{11}$$

$$\dot{N}_{12} = \tau_{1012} - \tau_{120} - \tau_{1213} + \rho_{12}$$

$$\dot{N}_{13} = \tau_{1213} + \rho_{13}$$

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TABLE 2b. VARIABLES FOR PATHWAY 2

SLUDGE TREATMENT PATHWAY - ANIMAL FEED SUPPLEMENT

POSITION	DEFAULT VALUE	VARIABLE	DEFINITION
		INPUT VARIABLES	
1	1.175E+7 3.1334E+2 3.9168E+7	ASCRS	Number of pathogens per kilogram of dry solids before Primary Sedimentation.
2	2.5331E+4	PLCAP	Plant capacity in kilograms of dry solids per day (raw sewage).
3	PLCAP*ASCRS	ASCIN	Number of pathogens per day entering pathway. If present, overrides first two variables.
4	0.2 0.01 0.15	FRPEF	Fraction of pathogens transferred from Primary Sedimentation to Primary Effluent.
5	70.	PRSOL	Percent solids desired at the end of the Drying Compartment.
6	0.05 0.005 0.025	FRDRN	Fraction of pathogens transferred to Drainage.
7	10.	WTRES4	Dry weight in kilograms of sludge transferred to Residue in Compartment 4.
8	150. 150. 1000.	DOSE	Radiation dose in kilorads from irradiator.
9	720.	DURTS	Duration in hours of Compartment 12, Transport and Storage.
10	24.	FEEDT	Duration in hours of Compartment 10, Feed Supplement Preparation.

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TABLE 2b. (continued)

POSITION	DEFAULT VALUE	VARIABLE	DEFINITION
11	0.18382	WTPAR2	Weight in kilograms of particulates generated in Compartment 2.
12	1.5318E+2	WTPAR5	Weight in kilograms of particulates generated in Compartment 5.
13	5.	WTRES	Weight in kilograms of Residue transferred from Compartment 6.
14	10.	WTRES8	Dry weight in kilograms of sludge transferred to Residue in Compartment 8.
15	0.2	WTPR11	Weight in kilograms of particulates generated in Compartment 11.
16	10.	WTRES9	Dry weight in kilograms of sludge tranferred to Residue in Compartment 9.
17	1.	WTRS12	Dry weight in kilograms of sludge transferred to Insect/ Rodent Dissemination.
18	10.	WTRS13	Dry weight in kilograms of sludge transferred to Residue in Compartment 13.
19	20.	TEMP	Ambient temperature throughout the pathway in degrees Celsius.
20	1.	TMILL	Duration in hours of Compartment 7, Transport to Feed Mill.
21	5.	DILFAC	Dilution factor of sludge in feed mix.
22	0.5 0.85 0.1	PKEPT	Fraction of pathogens lost during pelletization in Compartment 10 equals 1 - PKEPT.

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TABLE 2b. (concluded)

POSITION	DEFAULT VALUE	VARIABLE	DEFINITION
		OUTPUT VARIABLES	
23	(output)	TDRY	Time at completion of Compartment 3.
24	(output)	TIRP	Time at completion of Compartment 6.
25	(output)	TTFDM	Time at completion of Compartment 7.
26	(output)	TFESP	Time at completion of Compartment 10.
27	(output)	TTRST	Time at completion of Compartment 12.
28	(output)	PLCAP1	Dry weight in kilograms of sludge after Primary Sedimentation.
29	(output)	PLCAP2	Dry weight in kilograms of sludge after Transport to Feed Mill.
30	(output)	PLCAP3	Weight in kilograms of feed supplement.
31	(output)	NPFS	Pathogens per kilogram of feed supplement.

NOTES: The number of pathogens per day entering the pathway will default to PLCAP*ASCRS if no value is specified for ASCIN. If a value is specified for ASCIN, it will override the PLCAP* ASCRS value.

Whenever three default values are specified for any variable in the list above, the order is salmonellae, ascaris, poliovirus pathogen types. The appropriate default value will be selected to agree with the pathogen type being considered in a particular run.

All units of measure are in kilograms, degrees Celsius, or hours unless otherwise stated.

Variables labeled "output" are for internal computations and are not available to the user as input.

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irradiator that can deliver 1 megarad to 8 tons of sludge in one day (61).

d. The time required for the transport of dried irradiated sludge from the treatment plant to the feed mill is a user-specified value (TMILL). The user may include in this variable a time span representing storage of sludge prior to feed processing. The process functions provided in Compartment 7 are representative of population changes which would occur either during transport or during storage. By the same reasoning, the duration of Compartment 12, specified by variable DURTS, includes the time of storage and of transport.

e. The amount of airborne particulates generated during various parts of this pathway is derived from the United States Department of Labor, Occupational Health and Safety Administration's limit for the amount of total inert airborne particulates allowed in industrial processes (82). A particulate concentration of 15 milligrams per cubic meter of air is generated in a 10-meter-high volume above work areas considered in appropriate compartments in the pathway.

f. The ambient temperature during the pathway is provided by the model user and remains constant throughout the pathway. A default temperature of 20°C is provided.

g. The transfer of pathogens with residue, at various locations in the pathway, is computed by dividing the weight of the remaining residue by the total weight of sludge present in the compartment preceeding the residue compartment and then multiplying this fraction by the number of pathogens present. The default values provided in the model for weights of residues are estimates.

h. The sludge is processed into an animal feed supplement by a commercial feed-making process. It is assumed that the sludge is incorporated into a supplement that meets the complete nutritional requirements of a ruminant animal. The pelleted supplement is a one to five mixture of sludge and other feed ingredients such as vitamins, minerals, grain, and a binder such as molasses. During the process, the bulk dried sludge is ground to a suitable size and mixed with the other ingredients. The mixture is pelletized in a process that subjects the ingredients to a temperature of 80°C for 2 minutes. The prepared feed is then bagged or stored in bulk. The final product has a moisture content of 10 percent. During Feed Supplement Preparation, pathogen populations are affected by temperature and feed moisture content. Total weight of supplement produced from 1 day's sludge from a 30-MGD treatment plant is 76,272 kilograms.

i. TAU120 (τ_{120}) represents the consumption or removal of feed supplement by insects and rodents. One kilogram of feed supplement

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and associated pathogens are lost from the pathway each day while sludge (now incorporated in feed supplement) remains in Compartment 12.

j. The animal feed supplement manufactured by this pathway is fed to cattle in Pathway 7, Sludge Application Pathway - Animal Feed Supplement. The output variable NPF in position 31 represents the number of pathogens per kilogram of feed supplement at the end of the pathway. This value may be used as input to Pathway 7 by assigning it to ASCRS for that pathway and using the output variable PLCAP3, the final weight of feed supplement, in position 30 of Pathway 2 as the value for FDCONS in Pathway 7.

Compartment Descriptions

Compartment 1, PRIMARY SEDIMENTATION --

This pathway begins with the sedimentation of raw sewage. Sewage enters Compartment 1 at a constant rate during the 24-hour period necessary to accumulate 1 day's sludge. The percentage of sewage-associated pathogens retained with the solids fraction to become sludge-associated, when the default value for FRPEF is used, is based on a 2-hour retention time (77). For ease in modeling the rest of the treatment processes, the sludge is assumed to accumulate and to be transferred by TAU13 to Compartment 3, DRYING, as a unit at 24 hours. Pathogens not bound in the solids are transferred out of the pathway with PRIMARY EFFLUENT (TAU10). This transfer also occurs at 24 hours. The user may specify the fraction of input pathogens removed to PRIMARY EFFLUENT and thus the number retained with the sludge in the pathway by assigning a value to FRPEF. Because the retention is normally short and conditions are similar to those in the collection system, no change in pathogen populations has been defined for this compartment.

Time of first transfer into compartment - Beginning of pathway.

Time of last transfer out of compartment - 24 hours into pathway.

Process function - RHO1
Activated: Beginning of pathway.
Duration: 24 hours.
Rates: Salmonella: 0.0*N(1)/hour.
Ascaris: 0.0*N(1)/hour.
Poliovirus: 0.0*N(1)/hour.

Transfers into compartment -
TAU01 = ASCIN, Transfer occurs in hourly increments of 1/24 for 24 hours starting at the beginning of the pathway.

Transfers out of compartment -
TAU10 = FRPEF*N(1), Transfer occurs at 24 hours.
TAU13 = N(1) - TAU10, Transfer occurs at 24 hours.

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Compartment 2, PARTICULATES --

Particulates, to a level of 15 mg/m³ are generated at the end of DRYING into the volume above the sludge drying bed. The bed is assumed to be 1255 square meters in size to accommodate a 1-day production of sludge in a 30-centimeter deep layer. Particulate-associated pathogens are unaffected by process functions for 1 hour after particulate generation. The delay in process function activation permits risk assessment of maximum exposures during the time required for workers to remove sludge from the drying bed.

Time of first transfer into compartment - TDRY.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RHO2
Activated: TDRY + 1 hour.
Duration: Until all pathogens are depleted or the end of the pathway.
Rates: Salmonella: -0.46*N(2)/hour. (8)
Ascaris: -0.25*N(2)/hour. (22, 40, 74)
Poliovirus: -0.38*N(2)/hour. (88, 97)

Transfers into compartment -
TAU32 = (WTPAR2/PLCAP1)*N(3), Transfer occurs at TDRY.

Transfers out of compartment - None.

Compartment 3, DRYING --

The time required for DRYING is calculated from the solids concentration desired at the end of the process (a value specified by PRSOL) and the time required to achieve this solids concentration assuming sludge dries at 0.7 times the clear water evaporation rate (10, 84) after removal of free water by gravity drainage. The default solids concentration of 70 percent requires a drying time of 35 days. Drying time is calculated by the computer program and added to the 24 hours which constituted PRIMARY SEDIMENTATION to yield the output variable TDRY, the time at completion of this compartment.

Transfers are made from DRYING into Compartment 2 (TAU32), Compartment 6 (TAU36), Compartment 4 (TAU34) and to DRAINAGE (TAU30). Pathogens are removed from sludge with the effluent which drains away through the underdrain system of the drying bed during the first 48 hours of DRYING. Drainage is recirculated to the primary sedimentation basin within the treatment plant and is not considered as a compartment within the model. The fraction of total sludge pathogens transferred to DRAINAGE is an estimate.

The three transfers from the Drying Compartment into other compartments are all made at the end of drying. A weight of sludge and the pathogens associated with that sludge are transferred into Compartment 3,

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PARTICULATES, by TAU32. This simulates the generation of dust during removal of dried sludge from the drying beds. Another amount of sludge and the pathogens associated with it are left in the bed and cling to removal equipment. This is the weight of sludge transferred into Compartment 4, RESIDUE ON SITE AND EQUIPMENT, by TAU34. The remaining sludge and pathogens are transferred into Compartment 6, which represents the next treatment process, IRRADIATION. This transfer is accomplished by TAU36.

Significant calculations - The percent solids concentration of the drying sludge is calculated dynamically as a linear function using an initial value of 5 percent solids for wet sludge and the user-specified value of PRSOL as the end point.

Time of drying in days =

$$\frac{83.25 - (100 - (\%\ \text{solids} - 5.))}{1.35}\ ,\ \text{when } 20 < \%\ \text{solids} < 100.$$

$$\frac{95.0 - (100 - (\%\ \text{solids} - 5.))}{7.25}\ ,\ \text{when } 5 \leq \%\ \text{solids} \leq 20.$$

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Time of transfer into compartment - 24 hours into pathway.

Time of last transfer out of compartment - TDRY.

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Process function - RHO3
Activated: 24 hours into pathway.
Duration: Until TDRY.
Rates:
Salmonella: 0.13*N(3)/hour, for % solids of sludge $\leq$ 70 and 20 $\leq$ TEMP $\leq$ 40 to an upper limit of 1x10^9 per kilogram solids. This growth rate is 1/2 the rate of E.coli in sterile sludge. (76)
-0.05*N(3)/hour, for 70 < solids < 80 and TEMP < 40. (8)
-3.45*N(3)/hour, for % solids < 80 and TEMP > 40. (8, 93)
-0.46*N(3)/hour, for % solids $\geq$ 80. (8)
0.0*N(3)/hour, for % solids < 80 and TEMP $\leq$ 20.
Ascaris: -0.0012*N(3)/hour, for TEMP < 40 and % solids < 95. (40)
-1.535*N(3)/hour, for 40 $\leq$ TEMP $\leq$ 50 and % solids < 95. (7, 78)
-0.25*N(3)/hour, for % solids $\geq$ 95. (22, 40, 74)
Poliovirus: -0.01*N(3)/hour, for % solids < 65 and TEMP < 45. (44 ,87)
-0.33*N(3)/hour, for TEMP > 45. (88, 97)
-0.02*N(3)/hour, for % solids $\geq$ 65 and TEMP < 45. (87)

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Transfers into compartment -
TAU13 = N(1) - TAU10, Transfer occurs at 24 hours.

Transfers out of compartment -
TAU30 = FRDRN*N(3), Transfer occurs over a 48-hour period beginning at 24 hours.
TAU32 = (WTPAR2/PLCAP1)*N(3), Transfer occurs at TDRY.
TAU34 = (WTRES4/(PLCAP1 - WTPAR2))*N(3), Transfer occurs at TDRY + 1 hour.
TAU36 = N(3) - (TAU30 + TAU34 + TAU32), Transfer occurs at TDRY.

Compartment 4, RESIDUE ON SITE AND EQUIPMENT --

Not all sludge will be removed from the drying bed at the end of DRYING. Some fraction will remain as will the fraction of the pathogen population associated with it. Sludge will also adhere to removal equipment. The variable which estimates the weight of sludge left as residue, WTRES4, is a user-specifiable value. The calculation involved in determining the pathogen content of residue is done by the subroutine for Compartment 3 since the number of pathogens to be transferred must be known before the transfer takes place. The transfer takes place 1 hour after the end of DRYING, accounting for the time necessary to clear the bed.

Time of first transfer into compartment - TDRY + 1 hour.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RHO4
Activated: TDRY + 1 hour.
Duration: Until all pathogens are depleted or the pathway ends.
Rates: Salmonella: -0.46*N(4)/hour. (8)
The inactivation of salmonella in residue is assumed to occur at the rate for salmonella in drying sludge at greater than 80 percent solids.
Ascaris: -0.25*N(4)/hour. (22, 40, 74)
Poliovirus: -0.384*N(4)/hour. (88, 97)

Transfers into compartment -
TAU34 = (WTRES4/(PLCAP1 - WTPAR2))*N(3), Transfers occurs at TDRY.

Transfers out of compartment - None.

Compartment 5, PARTICULATES --

Particulates are generated from the sludge being loaded into the irradiator. A 10-meter high volume above a 126-square-meter loading pad is filled with 15 milligrams per cubic meter of pathogen carrying particules. As in other PARTICULATE compartments, the process function is not activated at generation but is delayed until the generating activity, in this case

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irradiation, is completed. This allows maximum exposure of sewage plant personnel to aerosols. The calculations which determine the number of pathogens entering this compartment are made in the subroutine for Compartment 6.

Time of first transfer into compartment - TDRY.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RHO5
  Activated: TIRP.
  Duration: Until all pathogens are depleted or the pathway ends.
  Rates: Salmonella: -0.46*N(5)/hour. (8)
    Ascaris: -0.25*N(5)/hour. (22, 40, 74)
    Poliovirus: -0.38*N(5)/hour. (88, 97)

Transfers into compartment -
  TAU65 = (WTPAR5/(PLCAP1 - WTRES4 - WTPAR2))*N(6), Transfer occurs at TDRY.

Transfers out of compartment - None.

Compartment 6, IRRADIATION --

This compartment describes the change in pathogen populations when sludge is subjected to gamma irradiation with cesium-137. The radiation dose to be delivered to the sludge is a variable (DOSE). The time required to deliver the selected dose to the sludge is calculated by the model using the processing capacity of the Sandia Irradiator for Dried Sewage Solids which can deliver a 1,000-krd dose to 8 tons (7272 kg) in a 24-hour period. The relationship between delivered dose and processing capacity is inversely proportional (i.e. at the lower dose of 500 krd, 16 tons (14,544 kg) can be processed per day). For example, if 20,000 kg of sludge is to be given a radiation dose of 150 krd, 0.4125 days, as is shown in the equation, would be required to process the sludge.

$$20000\ \text{kg} - \frac{1000\ \text{krd}}{150\ \text{krd}} \cdot 7272\ \frac{\text{kg}}{\text{day}} = 0.4125\ \text{days}$$

Responses of pathogens to irradiation, as interpredted in process function rates, assume that a fraction or multiple of the D_{10} value dose will result in the corresponding fraction or multiple pathogen reduction. The D_{10} value for salmonella is 54 krd. Therefore, a dose of 135 krd would result in a 2.5 order-of-magnitude reduction in the salmonella population. Once the total level of pathogen reduction has been determined as just described, the model distributes the reduction evenly over the time specified for sludge processing. The D_{10} values used in the model are: salmonella - 54 krd (8, 94), ascaris - 50 krd (7, 9), and poliovirus - 150 krd (85).

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Two components are included in the process functions for this compartment. RH06(1) models the effects of irradiation while RH06(2) models the effects of heat and dryness.

Sludge and associated pathogens are transferred from the IRRADIATION compartment of Compartment 5, PARTICULATES, by TAU65; Compartment 7, TRANSPORT TO FEED MILL, by TAU67; and to RESIDUE ON EQUIPMENT by TAU60. PARTICULATES, simulated by the transfer of an amount of sludge to Compartment 5, are generated by the loading of sludge into the irradiator. The concentration of particulates and the level of associated pathogens above the loading pad stays constant during the entire irradiation period. At TIRP, when all the sludge has been processed, the process functions for PARTICULATES are activated. At this time the transfer from IRRADIATION to Compartment 7 is also made. The bulk of the sludge is transported to the feed mill in that compartment. Some fraction of the irradiated sludge would be left as a residue on irradiation equipment after the treated sludge has been removed from the area. The user may supply the weight of sludge left behind by specifying a value for variable WTRES. The residue is assumed to continously cycle on the equipment and to be effectively removed from the pathway.

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Significant calculations - See signifcant calculations section for Pathway 1.

Time of first transfer into compartment - TDRY.

Time of last transfer out of compartment - TIRP.

Process function - RH06
Activated: TDRY.
Duration: Until TIRP.
Rates: RH06 = RH06(1) + RH06(2)
Salmonella: RH06(1) = ((-ln (10.E (DOSE/54.)))/(TIRP - TDRY))*N(6)/hour. (8, 94)
RH06(2) = -0.05*N(6)/hour, for TEMP < 40 and PRSOL < 80. (8)
= -3.45*N(6)/hour, for TEMP ≥ 40 and PRSOL < 80. (8, 93)
= -0.46*N(6)/hour, for PRSOL > 80 and any temperature. (8)
Ascaris: RH06(1) = ((-ln (10.E(DOSE/50.)))/(TIRP - TDRY))*N(6)/hour. (7, 9)
RH06(2) = 0.0*N(6)/hour, for TEMP < 40 and PRSOL < 95. (7, 9, 38)
= -1.5*N(6)/hour, for TEMP ≥ 40 and PRSOL < 95. (7, 78)
= -0.25*N(6)/hour, for PRSOL ≥ 95 and any temperature. (40, 22, 74)
Poliovirus: RH06(1) = ((-ln(10.E(DOSE/150.)))/(TIRP-TDRY))*N(6)/hour. (85)

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RH06(2) = -0.38*N(6)/hour, for TEMP ≥ 45. (88, 97)
= -0.01*N(6)/hour, for TEMP < 45. (87)

Transfers into compartment -
TAU36 = N(3) - (TAU30 + TAU32 + TAU34), Transfer occurs at TDRY.

Transfers out of compartment -
TAU60 = (WTRES/(PLCAP2 - WTPAR2 - WTRES4))*N(6), Transfer occurs at TIRP.
TAU65 = (WTPAR5/(PLCAP1 - WTPAR2 - WTRES4))*N(6), Transfer occurs at TDRY.
TAU67 = N(6) - (TAU60 + TAU65), Transfer occurs at TIRP.

Compartment 7, TRANSPORT TO FEED MILL --

After IRRADIATION, sludge is transported to the site of feed preparation. As with other transport compartments, the duration of this compartment may reflect storage of sludge by specifying an appropriate value for TMILL. The process functions modeling transport and storage effects on pathogens are the same. A residue would be left on transport vehicles or in storage facilities at the end of the activities in the compartment. This residue is transferred by TAU78 to Compartment 8. The rest of the sludge proceeds to Compartment 10.

Significant calculations -

PLCAP2 = PLCAP1 - (WTPAR2 + WTRES4 + WTPAR5 + WTRES)

Time of first transfer into compartment - TIRP.

Time of last transfer out of compartment - TTFDM.

Process function - RH07
Activated: TIRP.
Duration: TMILL.
Rates: Salmonella: -0.05*N(7)/hour, for PRSOL < 80 and TEMP < 45. (8)
-3.45*N(7)/hour, for PRSOL < 80 and TEMP ≥ 45. (8, 93)
-0.46*N(7)/hour, for PRSOL ≥ 80 and any temperature. (8)
0.0*N(7)/hour, for PRSOL < 80 and TEMP ≤ 20. No change in the population of salmonella is assumed for temperatures less than 20°C. The sludge is assumed to remain at a constant moisture after drying.
Ascaris: 0.0*N(7)/hour, for PRSOL < 95 and TEMP < 40. (7, 9, 38)

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-1.535*N(7)/hour, for PRSOL < 95 and 40 ≤ TEMP < 50. (7, 78)
-0.25*N(7)/hour, for PRSOL ≥ 65 and TEMP < 45. (22, 40, 74)

Poliovirus: -0.01*N(7)/hour, for PRSOL < 65 and TEMP < 45. (44, 87)
-0.38*N(7)/hour, for TEMP ≥ 45 and any PRSOL. (88, 97)
-0.02*N(7)/hour, for PRSOL ≥ 65 and TEMP < 45. (87)

Transfers into compartment -
TAU67 = N(6) - (TAU60 + TAU65), Transfer occurs at TIRP.

Transfers out of compartment -
TAU78 = (WTRES8/PLCAP2)*N(7), Transfer occurs at TTFDM.
TAU710 = N(7) - TAU78, Transfer occurs at TTFDM.

Compartment 8, RESIDUE ON EQUIPMENT --

Sludge and associated pathogens are transferred into this compartment at TTFDM when sludge is delivered to the feed mill. The transfer is calculated in Compartment 7 and the weight of sludge left as a residue may be specified by the user in variable WTRES8.

Time of first transfer into compartment - TTFDM.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RHO8
Activated: TTFDM.
Duration: Until all pathogens are depleted or the pathway ends.
Rates:
Salmonella: -0.46*N(8)/hour. (8)
Ascaris: -0.25*N(8)/hour. (22, 40, 74)
Poliovirus: -0.38*N(8)/hour. (88, 97)

Transfers into compartment -
TAU78 = (WTRES8/PLCAP2)*N(7), Transfer occurs at TTFDM.

Transfers out of compartment - None.

Compartment 9, RESIDUE ON EQUIPMENT --

During FEED SUPPLEMENT PREPARATION (Compartment 10) sludge contacts several pieces of equipment: grinders, mixing vats, steam pelletizers, bagging machines, etc. Some sludge and associated pathogens are left on this equipment when the feed supplement is moved to storage in Compartment 12. The amount is specified in WTRES9. Transfer into this compartment is accomplished by TAU109 at TFESP.

Time of first transfer into compartment - TFESP.

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Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RH09
Activated: TFESP.
Duration: Until all pathogens are depleted or the pathway ends.
Rates: Salmonella: -0.46*N(9)/hour. (8)
Ascaris: -0.25*N(9)/hour. (22, 40, 74)
Poliovirus: -0.38*N(9)/hour. (88, 97)

Transfers into compartment -
TAU109 = (WTRES9/PLCAP3)*(PKEPT*N(10)), Transfer occurs at TFESP.

Transfers out of compartment - None.

Compartment 10, FEED SUPPLEMENT PREPARATION --
The preparation of feed made with sludge was described in the general considerations section of this pathway description. When sludge is mixed with other feed ingredients, the pathogens associated with it are spread over the large resulting mass. This dilution of pathogens is defined by the variable DILFAC which is the denominator of a fraction representing the amount of sludge in the prepared feed supplement. For example, if the feed supplement is to be 20 percent sludge, the fraction will be 1/5 and DILFAC should be set to 5. The total weight of sludge containing feed is calculated in the program as shown below in significant calculations.

The duration of FEED SUPPLEMENT PREPARATION is a variable, FEEDT. At the feed mill used as a model in defining this pathway, the limiting step in feed preparation was pelletization. The equipment available could process 5 tons of feed each hour or 1 day's sludge (in a 20 percent feed) in 17 hours. The user may provide a value reflecting the processing capabilities of any feed mill.

Two components are included in the process function for this compartment. The changes in pathogen populations described by RH010 reflect the effects of dryness and temperature during most steps of the treatment process. There is an additional reduction in pathogens due to the pelletization process in which the feed is held at 80°C under pressure for at least 2 minutes. A 50 percent reduction of salmonella, a 15 percent reduction of ascaris, and a 90 percent reduction of poliovirus is provided by the variable PKEPT as part of transfer functions TAU109, TA1011, and TA1012. PKEPT is defined as the fraction of pathogens unaffected by pelletization. Since no references could be found in the available literature which adequately defined the effects of a process similar to feed pelletization, the user is encouraged to specify a value for PKEPT if relevant data are available to him.

Sludge and associated pathogens are transferred from FEED SUPPLEMENT PREPARATION to Compartment 9, RESIDUE ON EQUIPMENT, by TAU109; to Compartment 11, PARTICULATES, by TA1011; and to Compartment 12, TRANSPORT AND

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STORAGE, by TA1012. PARTICULATES are produced by most feed preparation steps. The limit of 15 mg/m^3 is generated at the start of compartment activities in the enclosed area of the feed mill, which is estimated to be 2250 cubic meters for our model mill (15 meters on a side by 10 meters high). The value for WTPR11 may be calculated to fit a different mill (area*10 meters*15 mg/m^3). RESIDUE is left on mill equipment when the prepared feed is removed from the site at TFESP. The bulk of the sludge, now part of a feed supplement, is transferred to storage at the same time.

Significant calculations -

PLCAP3 = DILFAC*(PLCAP2 - WTRES8)

Time of first transfer into compartment - TTFDM.

Time of last transfer out of compartment - TFESP.

Process function - RH010
Activated: TTFDM.
Duration: TFEED.
Rates: Salmonella: -0.46*N(10)/hour. (8)
Ascaris: 0.0*N(10)/hour, for TEMP < 40. (7, 9, 40)
-1.535*N(10)/hour, for 40 ≤ TEMP ≤ 50. (7, 78)
Poliovirus: -0.02*N(10)/hour. (87)

Transfers into compartment -
TAU710 = N(7) - TAU78, Transfer occurs at TTFDM.

Transfers out of compartment -
TAU109 = (WTRES9/PLCAP3)*(PKEPT*N(10)), Transfer occurs at TFESP.
TA1011 = (WTPR11/PLCAP3)*(PKEPT*N(10)), Transfer occurs at TFESP.
TA1012 = (PKEPT*N(10)) - (TAU109 + TA1011), Transfer occurs at TFESP.

Compartment 11, PARTICULATES --

PARTICULATES are generated at the start of FEED SUPPLEMENT PREPARATION. As in other particulate compartments, a level of 15 mg/m^3 is maintained for the duration of the preparation compartment. Particulate-associated pathogens are unaffected by process functions until TFESP when the prepared feed is removed from the site. The delay in process function activation allows for assessment of maximum risk.

Time of first transfer into compartment - TFESP.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration ends when the pathogen population is depleted or when the pathway ends.

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Process function - RHO11
Activated: TFESP.
Duration: Until all pathogens are depleted or the pathway ends.
Rates: Salmonella: -0.46*N(11)/hour. (8)
Ascaris: -0.25*N(11)/hour. (22, 40, 74)
Poliovirus: -0.38*N(11)/hour. (88, 97)

Transfers into compartment -
TA1011 = (WTPR11/PLCAP3)*(PKEPT*N(10)), Transfer occurs at TFESP.

Transfers out of compartment - None.

Compartment 12, TRANSPORT AND STORAGE --

Following preparation, the feed supplement is transported from the mill to a storage site. The user may specify a duration for this compartment which includes a time increment for both travel and storage. Process functions, which are based on moisture content of the finished feed and ambient temperature of the environment, are the same for both situations.

There are two transfers out of this final pathway compartment. TAU120 represents the consumption or simple removal of feed supplement by insects or rodents. One kilogram of feed supplement leaves the pathway for each day of storage. It is beyond the scope of this pathway to determine the effects of insect or rodent dissemination on pathogens. Therefore, this transfer is not to a defined compartment. TA1213 represents the transfer of a given weight of feed supplement to RESIDUE ON EQUIPMENT at the end of the pathway.

Time of first transfer into compartment - TFESP.

Time of last transfer out of compartment - TTRST.

Process functions - RHO12
Activated: TFESP.
Duration: DURTS.
Rates: Salmonella: -0.46*N(12)/hour. (8)
Ascaris: $-7.14*10^{-5}$*N(12)/hour, for PRSOL < 95 and TEMP < 40. (75)
-1.535*N(12)/hour, for PRSOL < 95 and and TEMP > 40. (7, 78)
-0.25*N(12)/hour, for PRSOL > 95. (22, 40, 74)
Poliovirus: -0.02*N(12)/hour. (87)

Transfers into compartment -
TA1012 = (PKEPT*N(10)) - (TAU109 + TA1011), Transfer occurs at TFESP.

Transfers out of compartment -
TAU120 = (WTRS12/(PLCAP3 - WTRES9 - WTRS11))*N(12), Transfer occurs once each day between TFESP and TTRST.

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TA1213 = (WTRS13/(PLCAP3 - WTRES9 - WTPR11))*N(12), Transfer occurs at TTRST.

Compartment 13, RESIDUE ON EQUIPMENT --

When the prepared feed supplement is sold or utilized, a residue remains on transport equipment and on the storage site. The user may specify the amount of residue by assigning a value to WTRS13. The pathway runs for 24 hours after the transfer into Compartment 13 is completed.

Time of first transfer into compartment - TTRST.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RHO13
Activated: TTRST.
Duration: 24 hours.
Rates: Salmonella: -0.46*N(13)/hour. (8)
Ascaris: -0.25*N(13)/hour. (22, 40, 74)
Poliovirus: -0.38*N(13)/hour. (88, 97)

Transfers into compartment -
TA1213 = (WTRS13/(PLCAP3 - WTRES9 - WTPR11))*N(12), Transfer occurs at TTRST.

Transfers out of compartment - None.

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PATHWAY 3 - SLUDGE TREATMENT PATHWAY - COMPOSTING OF RAW OR DIGESTED SLUDGE

General Considerations

This pathway describes the fate of sewage sludge pathogens during the treatment processes involved in the generation of compost from raw or anaerobically digested sludge. Figure 3 shows the process compartments and transfers which define this treatment regime. The differential equations which describe this pathway are presented in Table 3a. Each process function and transfer function is defined in the following section. Table 3b lists the definitions of and default values for the input variables used to define environmental factors. The general considerations and assumptions discussed below were made to facilitate model development.

a. As in Pathway 1, this pathway considers the total 1-day production of a 30-MGD sewage treatment plant. The sludge is assumed to be at 5 percent solids. The sludge may be anaerobically digested or the user may skip this process and input pathogen numbers directly to the dewatering compartment.

b. The number of pathogens entering the pathway each day in 30 million gallons of raw sewage is a user-supplied value that may be based on personal experience. The user may supply either the total number of pathogens entering the pathway (variable ASCIN) or both the number of pathogens per kilogram of sludge (ASCRS) and the amount of raw sludge being considered (PLCAP). Default values incorporated into the model represent average pathogen levels in municipal sewage (1, 4, 28, 32, 77). The user must specify one pathogen type for each model run.

c. The anaerobic digestion process is optional. If included in a pathway run, the compartment is assumed to be a batch process operating at mesophilic temperatures (25 to 35°C) and accommodating 1 day's sludge per batch. The user may specify process duration in variable PSTART. A default value of 30 days is provided in the model.

d. Raw or digested sludge is mechanically dewatered using an organic polymer as a chemical conditioning agent. The user may supply values for percent solids in the dewatered cake (variable CONC) and percent solids recovery (variable SOLIDS, which will determine the percent solids lost to extracted water) which reflect a given process or machine. The default values of the model are industry averages for vacuum filter, pressure filter, and centrifugal dewatering operations (84).

e. The ambient temperature during the pathway is provided by the model user and remains constant through the pathway. A default temperature of 20°C is provided in the model.

f. The transfer of pathogens with residue at various locations in this and all other pathways is computed by dividing the weight of

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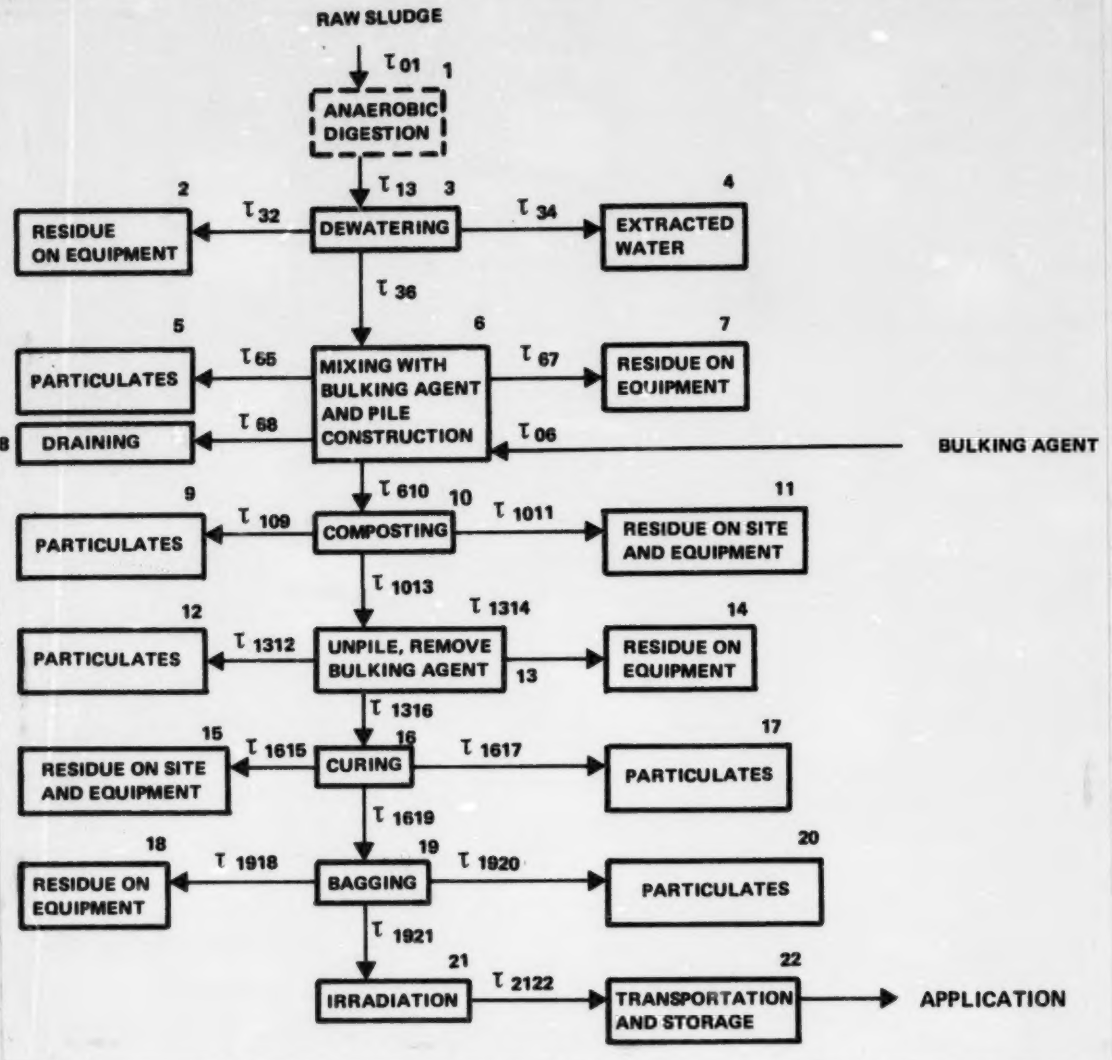
RAW SLUDGE
τ 01
1
ANAEROBIC DIGESTION
τ 13
2
3
4
τ 32
τ 34
RESIDUE ON EQUIPMENT
DEWATERING
EXTRACTED WATER
τ 36
5
6
7
τ 65
τ 67
PARTICULATES
MIXING WITH BULKING AGENT AND PILE CONSTRUCTION
RESIDUE ON EQUIPMENT
τ 68
τ 06
8
DRAINING
BULKING AGENT
τ 610
9
10
11
τ 109
τ 1011
PARTICULATES
COMPOSTING
RESIDUE ON SITE AND EQUIPMENT
τ 1013
12
τ 1314
14
τ 1312
PARTICULATES
UNPILE, REMOVE BULKING AGENT
13
RESIDUE ON EQUIPMENT
τ 1316
15
16
17
τ 1615
τ 1617
RESIDUE ON SITE AND EQUIPMENT
CURING
PARTICULATES
τ 1619
18
19
20
τ 1918
τ 1920
RESIDUE ON EQUIPMENT
BAGGING
PARTICULATES
τ 1921
21
22
τ 2122
IRRADIATION
TRANSPORTATION AND STORAGE
APPLICATION

Figure 3. Sludge Treatment Pathway - Composting of Raw or Digested Sludge

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TABLE 3a. DIFFERENTIAL EQUATIONS FOR PATHWAY 3

SLUDGE TREATMENT PATHWAY - COMPOSTING OF RAW OR DIGESTED SLUDGE

$$\dot{N}_1 = \tau_{01} - \tau_{13} + \rho_1$$

$$\dot{N}_2 = \tau_{32} + \rho_2$$

$$\dot{N}_3 = \tau_{13} - \tau_{32} - \tau_{34} - \tau_{36} + \rho_3$$

$$\dot{N}_4 = \tau_{34} + \rho_4$$

$$\dot{N}_5 = \tau_{65} + \rho_5$$

$$\dot{N}_6 = \tau_{06} + \tau_{36} - \tau_{65} - \tau_{67} - \tau_{68} - \tau_{610} + \rho_6$$

$$\dot{N}_7 = \tau_{67} + \rho_7$$

$$\dot{N}_8 = \tau_{68} + \rho_8$$

$$\dot{N}_9 = \tau_{109} + \rho_9$$

$$\dot{N}_{10} = \tau_{610} - \tau_{109} - \tau_{1011} - \tau_{1013} + \rho_{10}$$

$$\dot{N}_{11} = \tau_{1011} + \rho_{11}$$

$$\dot{N}_{12} = \tau_{1312} + \rho_{12}$$

$$\dot{N}_{13} = \tau_{1013} - \tau_{1312} - \tau_{1314} - \tau_{1316} + \rho_{13}$$

$$\dot{N}_{14} = \tau_{1314} + \rho_{14}$$

$$\dot{N}_{15} = \tau_{1615} + \rho_{15}$$

$$\dot{N}_{16} = \tau_{1316} - \tau_{1615} - \tau_{1617} - \tau_{1619} + \rho_{16}$$

$$\dot{N}_{17} = \tau_{1617} + \rho_{17}$$

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TABLE 3a. (concluded)

$$\dot{N}_{18} = \tau_{1918} + \rho_{18}$$

$$\dot{N}_{19} = \tau_{1619} - \tau_{1918} - \tau_{1920} - \tau_{1921} + \rho_{19}$$

$$\dot{N}_{20} = \tau_{1920} + \rho_{20}$$

$$\dot{N}_{21} = \tau_{1921} - \tau_{2122} + \rho_{21}$$

$$\dot{N}_{22} = \tau_{2122} + \rho_{22}$$

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TABLE 3b. VARIABLES FOR PATHWAY 3

SLUDGE TREATMENT PATHWAY - COMPOSTING OF RAW OR DIGESTED SLUDGE

POSITION	DEFAULT VALUE	VARIABLE	DEFINITION
		INPUT VARIABLES	
1	1.5668E+7 4.955E+2 5.549E+7	ASCRS	Number of pathogens per kilogram of dry solids after primary sedimentation.
2	1.5318E+4	PLCAP	Plant capacity in kilograms of dry solids.
3	PLCAP*ASCRS	ASCIN	Number of pathogens per day entering pathway. If present, overrides first two variables.
4	720.	PSTART	Pathway start flag. If the value is positive, it is equal to the duration of Compartment 1, Anaerobic Digestion. If the value = -1., Compartment 1 is not included in the pathway.
5	0.3	CONC	Percent solids desired at the end of Dewatering (fraction).
6	0.8	SOLIDS	Percent solids recovery of Dewatering (fraction).
7	0.0	WTRES2	Dry weight in kilograms of sludge transferred to Residue in Compartment 2.
8	0.0	COUNT	Number of pathogens per kilogram dry weight introduced with the bulking agent.
9	0.0	WTPAR5	Weight in kilograms of particulates generated in Compartment 5.
10	-2.	TRAIN	Selectable rain flag. -2. = no rain +2. = rain at PWATER+2 hours

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TABLE 3b. (continued)

POSITION	DEFAULT VALUE	VARIABLE	DEFINITION
11	5.	WTDRAN	Weight in kilograms of compost transferred to Drainage if rain occurs.
12	10.	WTRES7	Dry weight in kilograms of compost transferred to Residue in Compartment 7.
13	30.	TCOMPT	Time of Composting in days. A negative value implies windrow and a positive value implies static pile composting. The maximum value is 45.
14-28	VALUE OF TCOMPT NEG. POS. 32. 45. 43. 50. 50. 55. 54. 55. 58. 55. 60. 55. 60. 55. 60. 55. 60. 55. 60. 55. 60. 55. 60. 55. 60. 55. 60. 55. 60. 55.	TEMP1	Compost temperature values start on the third day after the start of Compartment 10 and continue, changing every third day, up to a maximum of 45 days (temperature at start of composting is ambient temperature of pathway). Example: If TCOMPT is negative, then position 14 equals 32, the temperature at day 3 of windrow composting.
29-43	APPLIES ONLY FOR TCOMP POSITIVE 55. 65. 65. 65. 65. 65. 65. 65. 70 70 70	TEMP2	

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TABLE 3b. (continued)

POSITION	DEFAULT VALUE	VARIABLE	DEFINITION
	70. 70. 70. 70.		
44	0.75	WTPAR9	Dry weight in kilograms of particulates generated in Compartment 9 for windrow composting.
45	10.	WTRS11	Dry weight in kilograms of compost transferred to Residue in Compartment 11.
46	0.75	WTPR12	Weight in kilograms of particulates generated in Compartment 12.
47	10.	WTRS14	Dry weight in kilograms of compost transferred to Residue in Compartment 14.
48	30.	TCURE	Duration in days of Compartment 16, Curing.
49	20.	CTEMP	Temperature of Curing Compartment.
50	10.	WTRS15	Dry weight in kilograms of compost transferred to Residue in Compartment 15.
51	0.75	WTPR17	Weight in kilograms of particulates generated in Compartment 17.
52	10.	WTRS18	Dry weight in kilograms of compost transferred to Residue in Compartment 18.
53	0.75	WTPR20	Weight in kilograms of particles generated in Compartment 20.

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TABLE 3b. (continued)

POSITION	DEFAULT VALUE	VARIABLE	DEFINITION
54	150. 150. 1000.	DOSE	Radiation dosage in kilorads from irradiator.
55	60.	PRSOL	Percent solids of compost during Irradiation.
56	30.	TSTORE	Duration in days of Compartment 22, Transportation and Storage Compartment.
57	20.	TSTEMP	Temperature of Transportation and Storage Compartment.
58	20.	TEMP	Ambient temperature throughout pathway in degrees Celsius.
59	-1.	RBA	Remove bulking agent flag. -1. = removal +1. = no removal
		OUTPUT VARIABLES	
60	(output)	PWATER	Time at completion of Compartment 3.
61	(output)	DRYWT	Dry weight in kilograms of compost pile.
62	(output)	TCOMPS	Time at completion of Compartment 10.
63	(output)	WTCOMP	Dry weight of compost at completion of Compartment 13.
64	(output)	TCURES	Time at completion of Compartment 15.
65	(output)	TIRPS	Time at completion of Compartment 21.
66	(output)	WTIRRD	Dry weight of bagged compost at completion of Compartment 19
67	(output)	NPKC	Number of pathogens per kilogram of compost.

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TABLE 3b. (concluded)

NOTES: The number of pathogens per day entering the pathway will default to PLCAP*ASCRS if no value is specified for ASCIN. If a value is specified for ASCIN, it will override the PLCAP*ASCRS value.

Whenever three default values are specified for any variable in the list above, the order is salmonellae, ascaris, poliovirus pathogen types. The appropriate default value will be selected to agree with the pathogen type being considered in a particular run.

All units of measure are in kilograms, degrees Celsius, or hours unless otherwise stated.

Variables labled "output" are for internal computations and are not available to the user as input.

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residue by the total weight of sludge or compost present in the compartment preceeding Residue on Equipment and then multiplying by the number of pathogens present. Residue weights used to calculate default values for the fractions transferred are only estimates. The model user is encouraged to provide transfers which reflect experience in these areas. Note that this pathway contains six different residue compartments. A naming convention was adopted. The variable representing the weight of material transferred into a residue compartment is WTRES or WTRS followed by the number of the residue compartment. WTRS is used when the compartment number is two digits. A similar convention was used for particulate transfer variables.

g. The amount of airborne particulates generated by various treatment processes assumes a concentration of 15 milligrams of sludge or compost per cubic meter of air in a volume equal to a 10-meter-high box over the site area. The composting site is assumed to be 0.5 hectares. This area was deemed sufficient to compost 1 day's dewatered sludge at 30 percent solids by either forced air static pile or windrow composting methods (20).

h. One part raw or digested sludge is mixed with three parts bulking agent before compost pile construction. The bulking agent may add pathogens to the pathway or may reduce the existing pathogen load per unit volume by a factor of four due to dilution. The model can simulate the use of a recoverable bulking agent, such as wood chips, which will be screened from composted sludge, or the used of a nonrecoverable bulking agent, such as previously composted sludge, which will permanently increase the volume of sludge handled in the rest of the pathway.

i. Drainage from the composting site will occur only in the event of a rain. The rain is flagged by the variable TRAIN. The weight of compost washed from the pile is specified by WTDRAN.

j. The process functions for the composting compartment are designed to accommodate both windrow and static pile composting. Since temperature was considered the most important factor determining inactivation of pathogens during composting, the model is designed to simulate the temperature regimes of both methods. In static pile composting, there is a temperature gradient from a cooler outside region to a warmer core. This gradient is simulated by dividing the compost pile volume into two fractions. Two-fifths of the pile, representing the outer 40 centimeters of a standard Beltsville structure (6 meters across base by 3 meters in height) (29), is assigned one set of lower temperatures over the composting period. The other three-fifths of the pile, representing the core, is assigned a second set of temperatures. A temperature for each fraction is specified for every 3-day time interval for up to 45 days of composting. In windrow composting, each pile is turned and mixed frequently. All material in such a pile is assumed to be at a uniform temperature at any specific

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time. Both temperature variables for any time interval are set to the same value. Default values are available for either composting method for a 30-day composting period in variables TEMP1 and TEMP2. The default temperature regimes are based on average recorded temperatures of windrow composting at the Los Angeles County Sanitation Districts site (43) and forced-aeration static pile composting at the USDA Beltsville site (29).

k. The use of default values to simulate windrow composting assumes the use of a nonrecoverable bulking agent. Default values for static pile composting provide for the removal of three-fourths of the total compost volume as bulking agent. The total pathogen load is retained by the compost.

l. Composting process functions continue during the curing process but the temperature of the total unpiled volume is uniform and constant. The user may specify the compartment duration (TCURE) and temperature (CTEMP). Default is 30 days at 20°C.

m. Moisture content of compost is assumed to be 60 percent from the beginning of the composting operation through irradiation when default values are used but may be set by assigning a value to PRSOL.

n. Each bag of compost weighs 50 pounds (22.7 kilograms).

o. Bagged compost is subjected to a user-specified dose of gamma irradiation. Default dosages provided in the model will give a three-log reduction in the total number of pathogens. The time required for the irradiation process depends upon the dose requested and the amount of compost to be processed. The time required to deliver the selected irradiation dose is based upon the design of the Sandia Laboratories' Irradiator for Dried Sewage Solids, a prototype irradiator that can deliver a 1-megarad dose to 8 tons of material per day (61).

p. The user may supply a temperature as well as compartment duration for the Transport and Storage Compartment. The moisture content of the bagged compost is assumed to remain at the value given PRSOL.

q. The use of compost manufactured by this pathway is simulated in Pathways 8 and 9, Sludge Application Pathway - Residential Garden Soil Amendment and Residential Lawn Soil Amendment, respectively. The value of the output variable in position 67 is the number of pathogens per kilogram of compost at the end of Pathway 3. This number can be assigned to position 1 (ASCRS) of the variable list of either Pathway 8 or 9 to link treatment and application pathways appropriately.

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Compartment Descriptions

Compartment 1, ANAEROBIC DIGESTION --

This treatment process is optional. The process functions of Compartment 1 will be activated only if the variable PSTART is set to a value greater than 1. This is the default condition. If the variable is set to -1., the pathogen population will be transferred unaltered to Compartment 2. The value assigned to PSTART also specifies the duration of digestion.

Time of first transfer into compartment - Start of pathway.

Time of last transfer out of compartment - PSTART.

Process function - RH01
Activated: Start of pathway.
Duration: PSTART.
Rates: Salmonella: -0.048*N(1)/hour. (57)
Ascaris: -0.00053*N(1)/hour. (22, 31, 32, 70)
Poliovirus: -0.089*N(1)/hour. (2, 59, 86)

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Transfers into compartment -
TAU01 = ASCRS, Transfer occurs at the beginning of the pathway.

Transfers out of compartment -
TAU13 = N(1), Transfer occurs at PSTART.

Compartment 2, RESIDUE ON EQUIPMENT --

Sludge to be composted is mechanically dewatered. Some fraction of the total amount processed will adhere to the equipment used. This fraction can be specified by the user. The sludge and associated pathogens are assumed to dry rapidly to greater than 80 percent solids. Process functions for this compartment reflect this dry state.

Time of first transfer into compartment - PWATER.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration ends when the pathogen population is depleted or when the pathway ends.

Process function - RH02
Activated: PWATER.
Duration: Until all pathogens are depleted or the pathway ends.
Rates: Salmonella: -0.46*N(2)/hour. (8)
Ascaris: -0.25*N(2)/hour. (22, 40, 74)
Poliovirus: -0.38*N(2)/hour. (88, 97)

Transfers into compartment -
TAU32 = (WTRES2/(PLCAP*SOLIDS))*N(3), Transfer occurs at PWATER.

Transfers out of compartment - None.

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Compartment 3, DEWATERING --

If ANAEROBIC DIGESTION is bypassed, the initial pathogen population input to the pathway will enter DEWATERING at the start of the pathway. If the sludge is digested, the pathogen population transfers into this compartment at PSTART hours. The time required to dewater any input amount of sludge is 24 hours. The percent solids of the dewatered cake is a variable, CONC, which may be set to model a particular process. The user may also specify what fraction of the input solids is lost to EXTRACTED WATER by specifying the percent solids recovery of the process (SOLIDS).

Transfers are made from DEWATERING into Compartment 2, RESIDUE ON EQUIPMENT, by TAU32; into Compartment 4, EXTRACTED WATER, by TAU34; and into Compartment 6, MIXING WITH BULKING AGENT AND PILE CONSTRUCTION, by TAU36. All of these transfers occur at time PWATER. In an operating treatment plant, sludge and associated pathogens would be constantly removed to EXTRACTED WATER during DEWATERING, but to simplify the model this transfer is made as a slug at the end of the process when the bulk of the cake is transferred to the composting site, leaving a small amount as residue.

Time of first transfer into compartment - PSTART.

Time of last transfer into compartment - PWATER.

Process function - RHO3
  Activated: PSTART.
  Duration: 24 hours.
  Rates: Salmonella: 0.0*N(3)/hour.
    Ascaris: 0.0*N(3)/hour.
    Poliovirus: 0.0*N(3)/hour.

Transfers into compartment -
  TAU13 = N(1), Transfer occurs at PSTART.

Transfers out of compartment -
  TAU32 = (WTRES2/(PLCAP*SOLIDS))*N(3), Transfer occurs at PWATER.
  TAU34 = (1. - SOLIDS)*N(3), Transfer occurs at PWATER.
  TAU36 = N(3) - (TAU32 + TAU34), Transfer occurs and PWATER.

Compartment 4, EXTRACTED WATER --

The water extracted from a mass of sludge carries a load of solids and therefore sludge-associated pathogens. This effluent is recycled into the treatment plant with raw influent. The model does not consider the fate of pathogens in this compartment and no process functions have been defined.

Time of first transfer into compartment - PWATER

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

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Process function - RHO4
Activated: PWATER.
Duration: Until all pathogens are depleted or the pathway ends.
Rates: Salmonella: 0.0*N(4)/hour.
Ascaris: 0.0*N(4)/hour.
Poloivirus: 0.0*N(4)/hour.

Transfers into compartment -
TAU34 = (1. - SOLIDS)*N(3), Transfers occurs at PWATER.

Transfers out of compartment - None.

Compartment 5, PARTICULATES --

Particulates, to a limit of 15 mg/m³, may be generated by the mixing and piling activities of Compartment 6 into a 10-meter high space above a 0.5 hectare composting site. Because sludge is usually too wet at this stage to produce much dust, the default value for variable WTPAR5 is 0.0. The user may specify a positive value for this variable if desired. As in other PARTICULATE compartments, the process function is not activated at generation but is delayed until the generating activity is completed. This allows maximum exposure of workers to aerosols. The calculations which determine the number of pathogens entering this compartment are made in the subroutine for Compartment 6.

Time of first transfer into compartment - PWATER + 1 hour.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RHO5
Activated: PWATER + 3 hours.
Duration: Until all pathogens are depleted or the pathways ends.
Rates: Salmonella: -0.46*N(5)/hour. (8)
Ascaris: -0.25*N(5)/hour. (22, 40, 74)
Poliovirus: -0.38*N(5)/hour. (88, 97)

Transfers into compartment -
TAU65 = (WTPAR5/DRYWT)*N(6), Transfer occurs at PWATER + 1 hour.

Transfers out of compartment - None.

Compartment 6, MIXING WITH BULKING AGENT AND PILE CONSTRUCTION --

This compartment describes the alteration in pathogen concentration which can result from the mixing of dewatered sludge with a bulking agent such as wood chips, municipal refuse, or previously composted sludge. The bulking agent can be a source of pathogens and/or can alter the concentration of sludge pathogens through dilution. The variable COUNT, which represents the number of pathogens per kilogram (dry weight) of bulking agent, defaults to zero. The bulking agent is assumed to be three times the dry weight of the sludge with which it is mixed.

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The addition of the bulking agent and any associated pathogens to this compartment is simulated by TAU06. There are four transfers out of this compartment. TAU65 simulates the possible production of particulates during compost pile construction. TAU67 represents the transfer of pathogens to RESIDUE ON EQUIPMENT. This transfer takes place at the end of compartment activities. TAU68, a transfer to DRAINAGE, occurs at the time of rain. If the variable TRAIN is set to +2., a weight of sludge and its associated pathogens (specified by WTDRAN) are transferred to DRAINAGE at PWATER + 2 hours. The default value for TRAIN is -2.; therefore, this transfer will not occur if default conditions are used. TAU610 moves the bulk of sludge, now mixed with bulking agent, to COMPOSTING. This transfer takes place at PWATER + 3 hours. From this point on the sludge mixture is referred to as compost.

No process functions are defined for this compartment because the activities assigned to it are completed in 3 hours and place no specific stress on the representative pathogens.

Significant calculations - The dry weight of the compost pile is calculated in this compartment:

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DRYWT = (PLCAP*SOLIDS - WTRES2)*4. where 4. = parts sludge + parts bulking agent.

Time of first transfer into compartment - PWATER.

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Time of last transfer out of compartment - PWATER + 3 hours.

Process function - RH06
Activated: PWATER.
Duration: PWATER + 3 hours.
Rates: Salmonella: 0.0*N(6)/hour.
Ascaris: 0.0*N(6)/hour.
Poliovirus: 0.0*N(6)/hour.

Transfers into compartment -
TAU06 = COUNT, Transfer occurs at PWATER.
TAU36 = N(3) - (TAU32 + TAU34), Transfer occurs at PWATER.

Transfers out of compartment -
TAU65 = (WTPAR5/DRYWT)*N(6), Transfer occurs at PWATER + 1 hour.
TAU67 = (WTRES7/DRYWT)*N(6), Transfer occurs at PWATER + 3 hours.
TAU68 = (WTDRAN/DRYWT)*N(6), Transfer occurs at PWATER + 2 hours if TRAIN = +2.

Compartment 7, RESIDUE ON EQUIPMENT --

A residue is left on the equipment used to mix the sludge with the bulking agent and to construct the pile. The user may specify the amount in WTRES7. The process function in this compartment is activated 2 hours after TAU67 is completed. This allows for human contact.

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Time of first transfer into compartment - PWATER + 3 hours.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RH07
Activated: PWATER + 5 hours.
Duration: Until all pathogens are depleted or the pathway ends.
Rates: Salmonella: -0.46*N(7)/hour. (8)
Ascaris: -0.25*N(7)/hour. (22, 40, 74)
Poliovirus: -0.38*N(7)/hour. (88, 97)

Transfers into compartment -
TAU67 = (WTRES7/DRYWT)*N(6), Transfer occurs at PWATER + 3 hours.

Transfers out of compartment - None.

Compartment 8, DRAINAGE --
If a compost pile is constructed of "wet" sludge or if the pile is saturated with rain water, excess water will drain from the pile, carrying suspended pathogens. To simulate either or both of these occurrences the user must set the variable TRAIN to +2. This variable is a flag which controls the transfer from Compartment 6 to this compartment by TAU68. When TRAIN is set to +2., TAU68 occurs at time PWATER + 2 hours, in the middle of the activities for Compartment 6. This fairly simulates the use of "wet" sludge and by way of a compromise simulates the effects of a rain.

The user may determine the amount of compost transferred to DRAINAGE by specifying the value of WTDRAN. Careful selection of this value can simulate rain of a known intensity or the effects of using a sludge with a known free water content. Under default conditions no transfer takes place because, while WTDRAN is set to 5., TRAIN is set to -2. The negative value selects for no rain.

DRAINAGE from a properly managed compost site is collected and lagooned or returned to the treatment plant. Therefore, no process functions are defined for this compartment.

Time of first transfer into compartment - PWATER + 2 hours.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RH08
Activated: PWATER + 2 hours.
Duration: Until all pathogens are depleted or the pathway ends.
Rates: Salmonella: 0.0*N(8)/hour.
Ascaris: 0.0*N(8)/hour.
Poliovirus: 0.0*N(8)/hour.

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Transfers into compartment -
TAU68 = (WTDRAN/DRYWT)*N(6), Transfer occurs at PWATER + 2 hours
if TRAIN = +2.

Transfers out of compartment - None.

Compartment 9, PARTICULATES --
The generation of PARTICULATES during composting depends on the type of compost method used. If static pile composting is selected (TCOMPT positive), no particulates are generated. If windrow composting is selected (TCOMPT negative), 15 milligrams of particulate matter per cubic meter of air are generated in a 10-meter high volume above a 0.5 hectare composting site once each day when the windrows are turned. As in other PARTICULATE compartments, the process function is not activated at the time TAU109 is completed but is delayed 2 hours. The variable WTPAR9 specifies the weight of compost which is transferred to PARTICULATES each day. Calculations which determine the number of pathogens entering this compartment are made in the subroutine for Compartment 10.

Time of first transfer into compartment - PWATER + 3 hours.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RH09
Activated: PWATER + 5 hours.
Duration: Until all pathogens are depleted or the pathway ends.
Rates: Salmonella: -0.46*N(9)/hour. (8)
Ascaris: -0.25*N(9)/hour. (22, 40, 74)
Poliovirus: -0.38*N(9)/hour. (88, 97)

Transfers into compartment -
TAU109 = (WTPAR9/(DRYWT - WTPAR5 - WTRES7 - WTDRAN))*N(10),
Transfer occurs at PWATER + 3 hours and then at 24-hour intervals until TCOMPS.

Transfers out of compartment - None.

Compartment 10, COMPOSTING --
Two methods of composting are modeled in this compartment. The user must select one method for each model run. Specifying a positive value for the variable TCOMPT selects static pile composting (this is the default condition) while a negative value selects the windrow method. The absolute value of this variable is the duration of COMPOSTING.

Static pile composting involves the specification of two temperature regimes to indicate conditions in an outer, cooler layer and in an inner, warmer core. These temperatures are specified for each 3-day interval. The program multiplies the process function for the lower temperature (TEMP1, variables in positions 14-28) for each 3-day interval by 0.4 to simulate the conditions in the outer two-fifths of the static pile and

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multiplies the process function for the higher temperature (TEMP2, variables in positions 29-43) by 0.6 to simulate the conditions in warmer pile core.

During windrow composting there is only one temperature regime (TEMP1, variables in positions 14-28, negative column) since the composting mass is kept homogeneous by daily turning. These turnings generate PARTICULATES, simulated by transfer of material from COMPOSTING to Compartment 9 by TAU109. The transfer occurs daily.

Transfers are also made from this compartment to Compartment 11, RESIDUE ON SITE AND EQUIPMENT (by TA1011) and to Compartment 13, UNPILE, REMOVE BULKING AGENT. These transfers occur at time TCOMPS.

Time of first transfer into compartment - PWATER + 3 hours.

Time of last transfer out of compartment - TCOMPS.

Process function - RH010
Activated: PWATER + 3 hours.
Duration: TCOMPT.
Rates: Salmonella: 0.0*N(10)/hour, for TEMP < 20.
0.066*N(10)/hour, for 20 ≤ TEMP < 40 to an upper limit of 1x10^9 per kilogram of compost. (62)
-0.027*N(10)/hour, for 40 ≤ TEMP < 60. (43)
-15.34*N(10)/hour, for 60 ≤ TEMP. (76)
Ascaris: 0.0*N(10)/hour, for TEMP < 20.
-0.00053*N(10)/hour, for 20 ≤ TEMP < 40. (83)
-1.53*N(10)/hour, for 40 ≤ TEMP < 60. (7, 78)
-197.4IN(10)/hour, for 60 ≤ TEMP. (9, 47, 51, 74, 78)
Poliovirus: 0.0*N(10)/hour, for TEMP < 20.
-0.10*N(10)/hour, for 20 ≤ TEMP < 40. (59)
-5.53*N(10/hour, for 40 ≤ TEMP < 60. (88)
-197.4*N(10)/hour, for 60 ≤ TEMP. (93)

Transfers into compartment -
TAU610 = N(6) - TAU67, Transfer occurs at PWATER + 3 hours.

Transfers out of compartment -
TAU109 = (WTPAR9/(DRYWT - WTPAR5 - WTRES7 - WTDRAN))*N(10), Transfer occurs at PWATER + 3 hours and then at 24-hour intervals until TCOMPS.
TA1011 = (WTRS11/(DRYWT - WTPAR5 - WTRES7 - WTDRAN))*N(10), Transfer occurs at TCOMPS.
TA1013 = N(10) - TA1011, Transfer occurs at TCOMPS.

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Compartment 11, RESIDUE ON SITE AND EQUIPMENT --

This compartment represents the residue which is left on the 0.5 hectare composting site and on windrow turning equipment after the bulk of the compost has been transferred to Compartment 13. The default value for WTRS11 is an estimate and is not associated with any particular composting method.

Time of first transfer into compartment - TCOMPS.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RHO11
Activated: TCOMPS.
Duration: Until all pathogens are depleted or the pathway ends.
Rates: Salmonella: -0.46*N(11)/hour. (8)
Ascaris: -0.25*N(11)/hour. (22, 40, 74)
Poliovirus: -0.38*N(11)/hour. (88, 97)

Transfers into compartment -
TA1011 = (WTRS11/(DRYWT - WTPAR5 - WTRES7 - WTDRAN))*N(10),
Transfer occurs at TCOMPS.

Transfers out of compartment - None.

Compartment 12, PARTICULATES --

PARTICULATES are generated by manipulations of the compost pile in Compartment 13. The transfer, TA1312, is made at the start of that compartment but the process function is delayed 2 hours. The default value of WTPR12 will permit 15 milligrams of compost particules per cubic meter in a 10-meter high volume above the 0.5 hectare composting site.

Time of first transfer into compartment - TCOMPS + 1 hour.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RHO12
Activated: TCOMPS + 3 hours.
Duration: Until all pathogens are depleted or the pathway ends.
Rates: Salmonella: -0.46*N(12)/hour. (8)
Ascaris: -0.25*N(12)/hour. (22, 40, 74)
Poliovirus: -0.38*N(12)/hour. (88, 74)

Transfers into compartment -
TA1312 = (WTPR12/WTCOMP)*N(13), Transfer occurs at TCOMPS + 1 hour.

Transfers out of compartment - None.

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Compartment 13, UNPILE, REMOVE BULKING AGENT --

After COMPOSTING is completed, the compost pile is broken down and the bulking agent, if it is reusable, is removed. The user may choose to model removal by setting RBA to -1. This is the default condition. A positive value for RBA will flag the program to model nonremoval. The difference in these two conditions is the weight of compost considered in subsequent compartments. Recovered bulking agent carries no pathogens out of the pathway. There are no process functions defined for this compartment because it is very short and not stressful.

There are three transfers out of this compartment. As in the two preceding compartments and in the two succeeding compartments of the process line (see Figure 3), PARTICULATES are generated at the start of compartment activities and RESIDUE ON EQUIPMENT is left when the bulk of the compost is transferred into the next processing compartment, CURING.

Significant calculations -

When RBA is set to +1. (no removal),

WTCOMP = (DRYWT - WTPAR5 - WTRE57 - WTDRAN - WTPAR9 - WTRS11)

When RBA is set to -1. (removal),

WTCOMP = (DRYWT - WTPAR5 - WTRES7 - WTDRAN - WTPAR9 - WTRS11)*0.25

where WTCOMP is the output variable giving the dry weight of compost at the end of this compartment.

Time of first transfer into compartment - TCOMPS.

Time of last transfer out of compartment - TCOMPS + 3 hours.

Process function - RH013
Activated: TCOMPS.
Duration: 3 hours.
Rates: Salmonella: 0.0*N(13)/hour.
Ascaris: 0.0*N(13)/hour.
Poliovirus: 0.0*N(13)/hour.

Transfers into compartment -
TA1013 = N(10) - TA1011, Transfer occurs at TCOMPS.

Transfers out of compartment -
TA1312 = (WTPR12/WTCOMP)*N(13), Transfer occurs at TCOMPS + 1 hour.
TA1314 = (WTRS14/WTCOMP)*N(13), Transfer occurs at TCOMPS + 2 hours.
TA1316 = N(16), Transfer occurs at TCOMPS + 3 hours.

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Compartment 14, RESIDUE ON EQUIPMENT --

A residue can be left on the equipment used to break down the compost pile and/or on the equipment used to separate bulking agent from compost. The value of WTRS14 is an estimate.

Time of first transfer into compartment - TCOMPS + 2 hours.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RH014
Activated: TCOMPS + 2 hours.
Duration: Until all pathogens are depleted or the pathway ends.
Rates:
Salmonella: $-0.46*N(14)$/hour. (8)
Ascaris: $-0.25*N(14)$/hour. (22, 40, 74)
Poliovirus: $-0.38*N(14)$/hour. (88, 97)

Transfers into compartment -
TA1314 = (WTRS14/WTCOMP)*N(13), Transfer occurs at TCOMPS + 2 hours.

Transfers out of compartment - None.

Compartment 15, RESIDUE ON SITE AND EQUIPMENT --

A residue will be left on the site used for curing and on the equipment used to transport compost to the BAGGING area. The pathogens associated with this residue will die off rapidly as the material dries. This phenomenon is simulated in the process function assigned to this and other RESIDUE compartments. The same rapid drying is assumed in PARTICULATE compartments after generating activities cease.

Time of first transfer into compartment - TCURES.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RH015
Activated: TCURES.
Duration: Until all pathogens are depleted or the pathway ends.
Rates:
Salmonella: $-0.46*N(15)$/hour. (8)
Ascaris: $-0.25*N(15)$/hour. (22, 40, 74)
Poliovirus: $-0.38*N(15)$/hour. (88, 97)

Transfers into compartment -
TA1615 = (WTRS15/(WTCOMP - WTPR12 - WTRS14))*N(16), Transfer occurs at TCURES.

Transfers out of compartment - None.

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Compartment 16, CURING --

CURING is a continuation of COMPOSTING; during the period when compost is in this compartment it dries at a rate of approximately 5 percent per day from a starting point of 60 percent solids (calculation is given below). The user may specify the duration of activities in this compartment by assigning a value to TCURE. The duration of CURING determines the final moisture content of the compost and affects the process functions of Compartments 21, IRRADIATION, and 22, TRANSPORT AND STORAGE. The user may also specify the temperature within the curing stack (CTEMP).

PARTICULATES are generated at the start of CURING (TA1617 into Compartment 17), and RESIDUE ON SITE AND EQUIPMENT (TA1615 into Compartment 15) is left when the bulk of the compost is transferred to BAGGING by TA1619 at time TCURES. The calculations to determine the number of pathogens transferred into PARTICULATE and RESIDUE compartments, given the respective variables WTPAR17 and WTRS15, are made in the subroutine for this compartment.

Significant calculations - The solids concentration of compost changes each day during CURING with

PRSOL = 100. - (-5.33*TDAY+60.)

where TDAY is the day of curing. The time at the end of the compartment is TCURES.

TCURES = TCOMPS + 3 hours + (TCURE*24hours)

Time of first transfer into compartment - TCOMPS + 3 hours.

Time of last transfer out of compartment - TCURES.

Process function - RHO16
Activated: TCOMPS + 3 hours.
Duration: TCURE.
Rates:
Salmonella:
-0.048*N(16)/hour, for $CTEMP < 20$ and $PRSOL < 80$. (8)
0.066*N(16)/hour, for $20 \leq CTEMP < 45$ and $PRSOL < 80$ to an upper limit of $1x10^6$ per kilogram compost. (62)
-3.45*N(16)/hour, for $CTEMP \geq 45$ and $PRSOL < 80$. (8, 93)
-0.46*N(16)/hour, for $PRSOL \geq 80$ and any temperature. (8)
Ascaris:
-0.00053*N(16)/hour, for $CTEMP < 40$ and $PRSOL < 95$. (83)
-1.54*N(16)/hour, for $40 \leq CTEMP \leq 60$ and $PRSOL < 95$.(7, 78)
-197.36*N(16)/hour, for $CTEMP > 60$ and any percent solids. (9, 47, 51, 74, 78)
-0.25*N(16)/hour, for $CTEMP \leq 60$ and $PRSOL \geq 95$. (22, 40, 74)

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Poliovirus: -0.010*N(16)/hour, for CTEMP < 45 and PRSOL < 65. (44, 87)
-0.019*N(16)/hour, for CTEMP < 45 and PRSOL > 65. (87)
-0.38*$\overline{N}$(16)/hour, for CTEMP $\geq$ 45 and any percent solids. (88, 97)

Transfers into compartment -
TA1316 = N(13), Transfer occurs at TCOMPS + 3 hours.

Transfers out of compartment -
TA1615 = (WTPR15/(WTCOMP - WTPR12 - WTRS14))*N(16), Transfer occurs at TCURES.
TA1617 = (WTPR17/(WTCOMP - WTPR12 - WTRS14))*N(16), Transfer occurs at TCOMPS + 4 hours.
TA1619 = N(16) - TA1615, Transfer occurs at TCURES.

Compartment 17, PARTICULATES --

Particulates, to a level of 15 mg/m^3, are generated at the start of CURING into a 10-meter high volume above a 0.5 hectare site. Particulate-associated pathogens are unaffected by process functions for 1 hour after particulate generation. The delay in process function activation permits risk assessment of maximum exposures during the time when workers are constructing the curing pile.

Time of first transfer into compartment - TCOMPS + 4 hours.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RH017
Activated: TCOMPS + 5 hours.
Duration: Until all pathogens are depleted or the pathway ends.
Rates: Salmonella: -0.46*N(17)/hour. (8)
Ascaris: -0.25*N(17)/hour. (22, 40, 74)
Poliovirus: -0.38*N(17)/hour. (88, 97)

Transfers into compartment -
TA1617 = (WTPR17/(WTCOMP - WTPR12 - WTRS14))*N(16), Transfer occurs at TCOMPS + 4 hours.

Transfers out of compartment - None.

Compartment 18, RESIDUE ON EQUIPMENT --

A residue will be left on the equipment used to bag compost. The amount specified in the default value for WTRS18 is an estimate. The pathogens associated with the compost residue die off rapidly from desiccation.

Time of first transfer into compartment - TCURES + 24 hours.

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Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process functions - RH018
Activated: TCURES + 24 hours.
Duration: Until all pathogens are depleted or the pathway ends.
Rates: Salmonella: -0.46*N(18)/hour. (8)
Ascaris: -0.25*N(18)/hour. (22, 40, 74)
Poliovirus: -0.38*N(18)/hour. (88, 97)

Transfers into compartment -
TA1918 = (WTRS18/(WTCOMP - WTPR12 - WTRS14 - WTRS15 - WTPR17)) *N(19), Transfer occurs at TCURES + 24 hours.

Transfers out of compartment - None

Compartment 19, BAGGING --

The cured compost is placed in plastic bags before being irradiated. This prevents recontamination of the product following IRRADIATION and also prevents further change in the moisture content. The BAGGING process takes 1 day and no process functions have been defined.

The bulk of the compost, now in 50-pound (22.7-kilogram) bags, transfers to IRRADIATION by TA1921 at TCURES + 24 hours. An amount specified by WTPR20 transfers to PARTICULATES at the beginning of the compartment, and another amount is left as RESIDUE ON EQUIPMENT (TA1918).

Significant calculations - The total weight of bagged compost which will be irradiated -

WTIRRD = WTPR12 - WTRS14 - WTRS15 - WTPR17 - WTRS18 - WTPR20.

Time of first transfer into compartment - TCURES.

Time of last transfer out of compartment - TCURES + 24 hours.

Process function - RH019
Activated: TCURES.
Duration: 24 hours.
Rates: Salmonella: 0.0*N(19)/hour.
Ascaris: 0.0*N(19)/hour.
Poliovirus: 0.0*N(19)/hour.

Transfers into compartment -
TA1619 = N(16) - TA1615, Transfer occurs at TCURES.

Transfers out of compartment -
TA1918 = (WTRS18/(WTCOMP - WTPR12 - WTRS14 - WTRS15 - WTPR17)) *N(19), Transfer occurs at TCURES + 2 hours.

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TA1920 = (WTPR20/(WTCOMP-WTPR12 - WTRS14 - WTRS15 - WTPR17))*N (19), Transfer occurs at TCURES + 2 hours.
TA1921 = N(19), Transfer occurs at TCURES + 24 hours.

Compartment 20, PARTICULATES --

BAGGING is assumed to be a mechanized process which produces dust. The default value for WTPR20 is based on generating 15 milligrams of particulates per cubic meter of air in a 10-meter high volume above the 0.5-hectare site. Particulate-associated pathogens are unaffected by process functions for 1 hour after generation to allow for human contact at a maximum level.

Time of first transfer into compartment - TCURES + 2 hours.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RH020
  Activated: TCURES + 3 hours.
  Duration: Until all pathogens are depleted or the pathway ends.
  Rates: Salmonella: -0.46*N(20)/hour. (8)
    Ascaris: -0.25*N(20)/hour. (22, 40, 74)
    Poliovirus: -0.38*N(20)/hour. (88, 97)

Transfers into compartment -
  TA1920 = (WTPR20/(WTCOMP - WTPR12 - WTRS14 - WTRS15 - WTPR17)) *N(19), Transfer occurs at TCURES + 2 hours

Transfers out of compartment - None.

Compartment 21, IRRADIATION --

This compartment describes the change in pathogen populations when sludge is subjected to gamma irradiation with cesium-137. The radiation dose to be delivered to the sludge is a variable (DOSE). The time required to deliver the selected dose to the sludge is calculated by the model using the processing capacity of the Sandia Irradiator for Dried Sewage Solids which can deliver a 1,000-krd dose to 8 tons (7272 kg) in a 24-hour period. The relationship between delivered dose and processing capacity is inversely proportional (i.e. at the lower dose of 500 krd, 16 tons (14,544 kg) can be processed per day). For example, if 20,000 kg of sludge is to be given a radiation dose of 150 krd, 0.4125 days, as is shown in the equation, would be required to process the sludge.

$$20000\ \text{kg} \div \left(\frac{1000\ \text{krd}}{150\ \text{krd}} \cdot 7272\ \frac{\text{kg}}{\text{day}}\right) = 0.4125\ \text{days}$$

Responses of pathogens to irradiation, as interpreted in process function rates, assume that a fraction or multiple of the D_{10} value dose

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will result in the corresponding fraction or multiple pathogen reduction. The D_{10} value for salmonella is 54 krd. Therefore, a dose of 135 krd would result in a 2.5 order-of-magnitude reduction in the salmonella population. Once the total level of pathogen reduction has been determined as just described, the model distributes the reduction evenly over the time specified for sludge processing. The D_{10} values used in the model are: salmonella - 54 krd (8, 94), ascaris - 50 krd (7, 9), and poliovirus - 150 krd (85).

Two components are included in the process functions for this compartment. RH021(1) models the effects of irradiation while RH021(2) models the effects of heat and dryness.

The compost and associated pathogens are transferred from the IRRADIATION compartment to Compartment 22, TRANSPORTATION AND STORAGE, by TA2122. No particulates are generated from this activity nor is any residue left on equipment because the compost is bagged.

Significant calculations - See significant calculations section of Pathway 1.

Time of first transfer into compartment - TCURES + 24 hours.

Time of last transfer out of compartment - TIRPS.

Process function - RH021
Activated: TCURES + 24 hours.
Duration: TIRP.
Rates: RH021 = RH021(1) + RH021(2)

Salmonella: RH021(1) = ((-ln(10.E(DOSE/54.)))/(TIRPS - TCURES - 25.))*N(21)/hour. (8, 94)
RH021(2) = -0.047*N(21)/hour, for TEMP < 45 and PRSOL < 80. (8)
= -3.45*N(21)/hour, for TEMP $\geq$ 45 and PRSOL < 80. (8, 93)
= -0.46*N(21)/hour, for PRSOL > 80 and any temperature. (8)

Ascaris: RH021(1) = ((-ln(10.E(DOSE/50.)))/(TIRPS - TCURES - 25.))*N(21)/hour. (7, 9)
RH021(2) = -0.00053*N(21)/hour, for TEMP < 40 and PRSOL < 95. (83)
= -1.54*N(21)/hour, for TEMP $\geq$ 40 and PRSOL < 95. (7, 78)
= -0.25*N(21)/hour, for PRSOL $\geq$ 95 and any temperature. (22, 40, 74)
= -197.5.36*N(21)/hour, for TEMP > 50 and any percent solids. (9, 47, 51, 74, 78)

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Poliovirus: RHO21(1) = ((-ln(10.E(DOSE/150.)))/(TIRPS - TCURES - 25.))*N(21)/hour. (85)
RHO21(2) = -0.38*N(21)/hour, for TEMP $\geq$ 45. (88, 97)
= -0.01*N(21)hour, for TEMP < 45. (44, 87)

Transfers into compartment -
TA1921 = N(19), Transfer occurs at TCURES + 24 hours.

Transfers out of compartment -
TA2122 = N(21), Transfer occurs at TIRPS.

Compartment 22, TRANSPORTATION AND STORAGE --

Following IRRADIATION, the bagged compost will be taken to a distribution point such as a warehouse and stored until used. Process functions are the same during either transport or storage and are determined by the temperature in the compartment and the percent solids of the bagged compost. The user may specify a temperature for this compartment (TSTEMP) which may differ from the ambient temperature for the rest of the pathway. He may also specify the duration of the activities in this compartment by assigning a value to TSTORE. The compartment is the last one for Pathway 3.

Time of first transfer into compartment - TIRPS.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathway terminates.

Process function - RHO22
Activated: TIRPS.
Duration: TSTORE.
Rates: Salmonella: 0.0*N(22)/hour, for TSTEMP < 20 and PRSOL < 80. (8)
0.066*N(22)/hour, for 20 $\leq$ TSTEMP < 45 and PRSOL < 80, up to a maximum of 1×10^6 per kilogram of compost. (62)
-3.45*N(22)/hour, for TSTEMP $\geq$ 45 and PRSOL < 80. (8, 93)
-0.46*N(22)/hour, for any temperature and PRSOL > 80. (8)
Ascaris: -0.00053*N(22)/hour, for TSTEMP < 40 and PRSOL < 95. (83)
-1.54*N(22)/hour, for 40 $\leq$ TSTEMP $\leq$ 60 and PRSOL < 95. (7, 78)
-197.36*N(22)/hour, for TSTEMP > 60 and any percent solids. (9, 47, 51, 74, 78)
-0.25*N(22)/hour, for TSTEMP $\leq$ 60 and PRSOL $\geq$ 95. (22, 40, 74)

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Poliovirus: -0.10*N(22)/hour, for TSTEMP < 45 and PRSOL < 65. (59)
-0.019*N(22)/hour, for TSTEMP < 45 and PRSOL > 65. (87)
-0.38*N(22)/hour, for TSTEMP ≥ 45 and any percent solids. (88, 97)

Transfers into compartment -
TA2122 = N(21), Transfer occurs at TIRPS.

Transfers out of compartment - None.

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PATHWAY 4 - SLUDGE APPLICATION PATHWAY - FERTILIZER FOR CROPS DESTINED FOR HUMAN CONSUMPTION

General Considerations

This pathway describes the fate of sewage sludge pathogens after the application of dried, raw or anaerobically digested sludge to a 1-hectare field which will be planted in vegetable crops destined for human consumption. Figure 4 shows the process compartments and transfers which define this application regime. The differential equations which describe this pathway are presented in Table 4a. Each process function (ρ_i) and transfer function (τ_i) is defined in the following section, where each compartment is described in detail.

Process functions are designated by RHO followed by the compartment number, so that RHO1 would designate the change in pathogen population occurring in Compartment 1. The Greek symbol "ρ" with a subscript to indicate the appropriate compartment number is used in equations. Transfer functions are designated by TAU followed by the number of the compartment from which the transfer is made and then the number of the compartment into which the transfer is going. TAU32 designates the transfer from Compartment 3 into Compartment 2. The Greek symbol "τ" with a subscript is used in equations and in the pathway diagrams (Figures 1-13) to indicate defined transfers. TA followed by the appropriate compartment numbers is substituted for TAU when more than three digits are needed to define a transfer. This shortening is necessitated by program language limits. Labeled arrows are used in pathway diagrams to help identify the direction of flow between model compartments. Each compartment is descriptively named to indicate the sort of process being modeled by the corresponding computer subprogram. In pathway diagrams, the compartment number usually appears on the upper right hand corner of the box representing the compartment.

Table 4b lists the definitions of and default values for the input variables used to define environmental factors which affect process and transfer functions. The model user may supply a value for any input variable and, thus, set the program to model a specific situation of concern. Table 4b also lists output variables generated by the computer program. These variables are not available to the user as input but are often used in pathway descriptions to define time increments and pathogen levels. The general considerations and assumptions discussed below were made to facilitate model development.

a. The duration of the pathway is determined by the user. The pathway terminates after crops are harvested, and the user may specify growth periods appropriate to ripen a chosen crop. The default pathway duration of 1680 hours (70 days) is an average value when the three vegetables used as examples are grown under adequate irrigation in the sunny Southwest (18, 67). Varying pathway duration by changing the value of THARV will simulate other climates.

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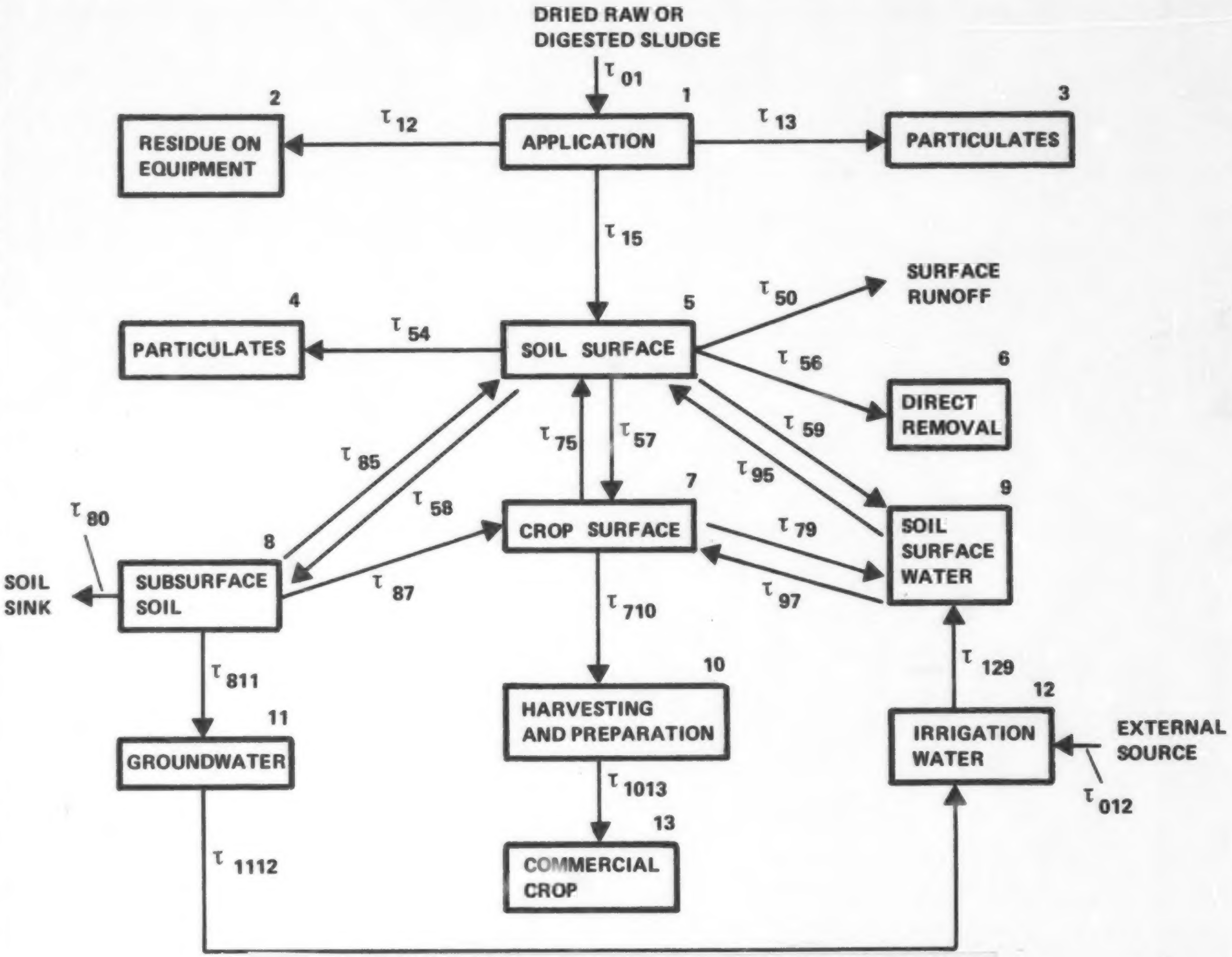
DRIED RAW OR DIGESTED SLUDGE
τ 01
1
APPLICATION
τ 12
2
RESIDUE ON EQUIPMENT
τ 13
3
PARTICULATES
τ 15
5
SOIL SURFACE
τ 54
4
PARTICULATES
τ 50
SURFACE RUNOFF
τ 56
6
DIRECT REMOVAL
τ 59
τ 95
9
SOIL SURFACE WATER
τ 75
τ 57
7
CROP SURFACE
τ 79
τ 97
τ 85
τ 58
τ 87
τ 80
8
SUBSURFACE SOIL
SOIL SINK
τ 811
11
GROUNDWATER
τ 1112
τ 710
10
HARVESTING AND PREPARATION
τ 1013
13
COMMERCIAL CROP
τ 129
12
IRRIGATION WATER
EXTERNAL SOURCE
τ 012

Figure 4. Sludge Application Pathway - Fertilizer for Crops Destined for Human Consumption

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TABLE 4a. DIFFERENTIAL EQUATIONS FOR PATHWAY 4

SLUDGE APPLICATION PATHWAY - FERTILIZER FOR CROPS DESTINED FOR HUMAN CONSUMPTION

$$\dot{N}_1 = \tau_{01} - \tau_{12} - \tau_{13} - \tau_{15} + \rho_1$$

$$\dot{N}_2 = \tau_{12} + \rho_2$$

$$\dot{N}_3 = \tau_{13} + \rho_3$$

$$\dot{N}_4 = \tau_{54} + \rho_4$$

$$\dot{N}_5 = \tau_{15} + \tau_{75} + \tau_{85} + \tau_{95} - \tau_{50} - \tau_{54} - \tau_{56} - \tau_{57} - \tau_{58} - \tau_{59} + \rho_5$$

$$\dot{N}_6 = \tau_{56} + \rho_6$$

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$$\dot{N}_7 = \tau_{57} + \tau_{87} + \tau_{97} - \tau_{75} - \tau_{79} - \tau_{710} + \rho_7$$

$$\dot{N}_8 = \tau_{58} - \tau_{80} - \tau_{811} - \tau_{85} - \tau_{87} + \rho_8$$

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$$\dot{N}_9 = \tau_{59} + \tau_{79} + \tau_{129} - \tau_{95} - \tau_{97} + \rho_9$$

$$\dot{N}_{10} = \tau_{710} - \tau_{1013} + \rho_{10}$$

$$\dot{N}_{11} = \tau_{811} - \tau_{1112} + \rho_{11}$$

$$\dot{N}_{12} = \tau_{1112} + \tau_{012} - \tau_{129} + \rho_{12}$$

$$\dot{N}_{13} = \tau_{1013} + \rho_{13}$$

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TABLE 4b. VARIABLES FOR PATHWAY 4

SLUDGE APPLICATION PATHWAY - FERTILIZER FOR CROPS DESTINED FOR HUMAN CONSUMPTION

POSITION	DEFAULT VALUE	VARIABLE	DEFINITION
		INPUT VARIABLES	
1	1.95E+7 4.95E+2 6.52E+7	ASCRS	Number of pathogens per kilogram of applied sludge.
2	3.5E+4	APRATE	Application rate of sludge in kilograms per hectare.
3	ASCRS*APRATE	ASCIN	Total number of pathogens entering pathway. If present, overrides first two variables.
4	20.	TEMP	Ambient temperature throughout pathway in degrees Celsius.
5	5.	WTPAR3	Weight in kilograms of particulates generated in Compartment 3.
6	10.	WTRES2	Dry weight in kilograms of sludge transferred to Residue in Compartment 2.
7	-2.	TRAIN	Time in hours of arbitrary rain. (If -2., there is no rain.)
8	0.0085 0.0005 0.0085	FRRAIN	Fraction of total pathogens transferred from Soil Surface to Surface Runoff by rain.
9	1440.	TWIND	Time in hours of arbitrary windstorm. Values between 50 days and THARV are permissible. (If -2., there is no windstorm.)
10	15.	WTPAR4	Dry weight in kilograms of particulates generated from Soil Surface during windstorm.
11	0.0125	WTDRM	Weight of transfer from Soil Surface to Direct Removal before THARV.

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TABLE 4b. (continued)

POSITION	DEFAULT VALUE	VARIABLE	DEFINITION
12	1680.	THARV	Time of harvest in hours.
13	0.05	WTDRMH	Weight of transfer from Soil Surface to Direct Removal at THARV.
14	0.05 0.01 0.05	SUSPND	Fraction of Soil Surface associated pathogens suspended in Soil Surface Water.
15	1.	CROP	Type of crop being grown: +1. = Above-ground 0. = On-ground -1. = Below-ground
16	1.19E-8	FCROP1	Fraction of transfer from Soil Surface to above-ground Crop Surface.
17	0.06	FCROP2	Fraction of transfer from Soil Surface to on-ground Crop Surface.
18	9.66E-4	FCROP3	Fraction of transfer from Soil Surface to below-ground Crop Surface.
19	0.001 0.0 0.83	SUBSOL	Fraction of transfer from Soil Surface to Subsurface Soil.
20	2.	FILTR8	Infiltration rate of Soil Surface Water in centimeters per hour.
21	0.0001	FSUR1	Fraction of transfer from Soil Surface Water to above-ground Crop Surface.
22	0.012	FSUR2	Fraction of transfer to on-ground Crop Surface.
23	0.0	FSUR3	Fraction of transfer to below-ground Crop Surface.

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TABLE 4b. (concluded)

POSITION	DEFAULT VALUE	VARIABLE	DEFINITION
24	0.0	FRSUR	Fraction of transfer from Subsurface Soil to Soil Surface. A positive value indicates cultivation or another specific soil disturbance.
25	0.0	FRGRND	Fraction of transfer from Subsurface Soil to Groundwater.
26	1.0E-6	DILGRN	Groundwater and use dilution.
27	0.5	DILIRR	Fraction of irrigation water from Groundwater.
28	6.	DEPTH	Depth of irrigation water in centimeters.
29	0.0	COUNT	External Source pathogen input into irrigation water (total population).
		OUTPUT VARIABLES	
30	(output)	FPCU	Final pathogen count per crop unit.
31	(output)	TIRRG	Time of irrigation.

NOTES: The number of pathogens per day entering the pathway will default to APRATE*ASCRS if no value is specified for ASCIN. If a value is specified for ASCIN, it will override the APRATE* ASCRS value.

Whenever three default values are specified for any variable in the list above, the order is salmonellae, ascaris, poliovirus pathogen types. The appropriate default value will be selected to agree with the pathogen type being considered in a particular run.

All units of measure are in kilograms, degrees Celsius, or hours unless otherwise stated.

Variables labeled "output" are for internal computations and are not available to the user as input.

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b. The ambient temperature of the environment is specified for each run of the model by the variable TEMP and remains constant throughout. The default ambient temperature is 20°C.

c. The amount of sludge applied to the field (APRATE) and the concentration of pathogens in that sludge (ASCRS) are user-specifiable variables. The model allows one application of sewage sludge fertilizer which is turned into the soil before crops are seeded. There are no additional applications of sludge prior to harvest. Default values are based on adding a moderate amount of sludge (48), approximately 34 dry metric tons/hectare, to the field. The default values for the number of pathogens present in the sludge reflect a conservative "worst case" and are set equal to the concentration of each pathogen in raw sludge from a municipal treatment system (1, 4, 28, 32, 77). The value of output variable PTOTL, position 20 of Pathway 1's P-array, is equal to the number of pathogens per kilogram of sludge at the end of a run of Pathway 1. The user may run Pathway 1 for one of the three pathogens and then use the output value of PTOTL as the value for ASCRS, the variable in position 1 of Pathway 4's P-array. ASCRS determines the number of pathogens per kilogram of sludge applied to the field as fertilizer. In this way, Pathways 1 and 4 may be linked and a selected pathogen followed through treatment and application of sludge.

d. The area of the field is set at 1 hectare. This area was used in determining plant spacing, leaf surface exposures, crop yields, etc.

e. The pathway is defined for three types of crops:
Above-ground -- vegetables which ripen on bushy plants above the ground and which do not directly contact either the soil surface or irrigation water during growth. Hybrid tomatoes were used as the example. Fifty-four rows of tomatoes, spaced 1.5 meters apart with plants on 0.5-meter centers within each row, fit in the field and will produce 2.2 kilograms of tomatoes per meter of row (34). Tomatoes were modeled as perfect spheres 10 centimeters in diameter and weighing 0.2 kilogram each (15).

On-ground -- vegetables which grow on spreading vines or runners and which lie directly on the ground during most of their growing period. These vegetables are in direct contact with the surface soil and may be covered by irrigation water if the depth of irrigation exceeds the size of the vegetable. Zucchini squash was used as the example. The crop is planted with 1 meter between rows and 0.5 meter between plants within the rows, so that there are 200 plants per 1000 meters of row (34, 15). Each plant will produce two squash which were modeled as perfect cylinders 20 centimeters in diameter and weighing 0.2 kilogram. One-half the area of each squash is assumed to rest directly on the soil surface.

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Below-ground -- root and tuber vegetables which develop completely underground. Carrots were used as the example of below-ground crops. The 1-hectare field will allow 200 rows of carrots spaced 0.5 meter apart with 0.1 meter between thinned plants. (15, 34) Carrots are assumed to be perfect cylinders 20 centimeters long by 2.5 centimeters in diameter and weighing 0.1 kilogram. Because of their length, one-half of each carrot extends into the subsurface soil.

The user must select one crop type for each run of the pathway by specifying the value of CROP. The default value of +1. selects the above-ground crop type.

f. At the time of application, sludge is disked into the soil - an operation which creates two distinct soil layers. The upper 10 centimeters of soil is a homogeneous mixture of sludge and soil. This zone is affected by changing temperatures and dries after each irrigation. The next 50 centimeters is the subsurface soil layer. This zone has a constant temperature and moisture level. Pathogens enter this zone with percolating water. Transfers of pathogens from both soil layers to crop surfaces are under some constraints, discussed below.

g. Pathogens in the surface soil are transferred to above-ground crops once during the crop cycle, when a wind storm stirs up dust in a 10-meter high volume above the field. A fraction of this dust, in proportion to the volume of tomatoes relative to the volume of the field, settles on tomatoes. As with particulates throughout all model pathways, the dust is assumed to be at a concentration of 15 milligrams per cubic meter (82). Pathogens in the dust on above-ground crop surfaces will die off at a constant rate until crop harvest, and a fraction will fall off the fruit and return to the soil surface. Pathogens from subsurface soil will not contact above-ground crops.

On-ground crops are in constant contact with surface soil and are considered to be at equilibrium with the soil, transferring as many pathogens to soil as are transferred from the soil, until harvest when a percentage of the total pathogen content of the surface soil layer is transferred to the crop. That percentage is based on a ratio of crop area in contact with the soil to the area of the field. All crops are assumed to be nonexistent until day 50 and from then on to be full sized at harvest regardless of the harvest time selected. Pathogens in the subsurface soil do not contact on-ground crops.

Crops growing below ground are part of the soil until harvest when a fraction of both surface and subsurface soil pathogens are transferred to the crop. The ratio of the volume of the crop in each soil layer to the total volume of each layer determines the number of pathogens transferred.

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h. Default values for soil factors describe a sandy loam soil. The water infiltration rate (26, 33) and water holding capacity of the soil (80) are functions of soil type and determine the duration of the soil surface water compartment. Values used in the transfer of pathogens from the surface to subsurface soil zones were based on the ability of sandy loam soils to filter and adsorb particles of different sizes carrying different charges. Variables are provided in the model for soil factors and the fractions of transfer between pathway compartments. The user may specify values for these variables which describe other soil types.

i. The field is irrigated after sludge application and every 7 days thereafter. The field is flooded to a uniform depth. The water then infiltrates the soil at a constant and uniform rate. The default depth of irrigation (DEPTH) is calculated to allow infiltration of water 60 centimeters below the surface (6), precluding transfer of pathogens to groundwater. Increasing the amount of irrigation water applied would lead to a transfer to groundwater. The user would have to supply a value for FRGRN if such a transfer were desired.

During each irrigation, infiltrating water will saturate the soil as it percolates downward until the trailing edge transverses the surface soil zone. At this time, the surface soil layer will be at field capacity with the soil holding the maximum amount of water that will not drain away due to gravity. The upper 10-centimeter layer of soil then dries at a rate calculated for sandy loam soils in the Southwest (96). The subsurface soil is always at field capacity.

j. The moisture content and temperature of the environment determine the growth and/or inactivation of pathogens.

k. Irrigation water may be pumped from groundwater influenced by irrigation, may be from the diversion of surface flows, or may be a combination of water from both sources. Variables included in the pathway indicate the dilution factor of pathogens present in groundwater (DILGRN) and the fraction of the total irrigation from this source (DILIRR). The number of pathogens from an external source (COUNT) can be specified.

l. Crop type affects transfers of pathogens from soil surface water. A fraction of the pathogens in surface soil becomes suspended in surface water at the beginning of irrigation. Default values for this transfer are estimates. The user may specify supportable values if they are available. While there is standing water in the field, splashing results in transfers of pathogens suspended in soil surface water to above-ground crops. On-ground crops are submerged in the irrigation water and retain a portion of suspended pathogens. The number is related to the area of the field occupied by the crop. Since pathogens suspended in the surface

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water return to the soil as irrigation water percolates into the soil, below-ground crops receive no direct transfers from soil surface water.

m. Workers enter the field during planting, irrigation, and harvest and directly remove surface soil which adheres to shoes, clothing and skin. Default values for direct removal are estimates of contact. The user may supply values which reflect his own experience. Note that two variables are provided, one for removals before harvest (WTDRM) and one for removal during harvest (WTDRMH).

n. Transfers from subsurface soil to surface soil do not occur when the pathway default values are used. The user may specify a value for the variable FRSUR to reflect cultivation or other physical disturbance of the soil profile. Specified transfers will occur at 2-week intervals.

o. An optional rain is included in the pathway. If requested, the rain will produce surface runoff which removes a fraction of surface-soil-associated pathogens. The values incorporated in the model for intensity and duration of rainfall result in 1/2 inch of rain on the field and produce a moderate runoff calculated for a sandy loam soil under cultivaton (14).

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Compartment Descriptions

Compartment 1, APPLICATION --

Sludge is applied to a 1-hectare field. The amount is determined by the variable APRATE and the pathogen content by the variable ASCRS. The field is then plowed to incorporate the sludge and sludge-associated pathogens evenly throughout the upper 10 centimeters of soil. This layer is the SOIL SURFACE modeled in Compartment 5. After plowing, the field is planted in one of three crops; an above-ground crop represented by hybrid tomatoes, an on-ground crop represented by zucchini squash, or a below-ground crop represented by carrots. The type of crop is determined by the variable CROP.

The APPLICATION compartment exists primarily to provide for the initial transfers into other compartments. It only lasts 2 hours and there are no process functions associated with it (i.e., no pathogen reduction). Sludge and sludge-associated pathogens are transferred from this compartment to Compartment 2, RESIDUE ON EQUIPMENT, by TAU12; to Compartment 3, PARTICULATES, by TAU13; and to Compartment 5, SOIL SURFACE, by TAU15. PARTICULATES are generated during the application and plowing activities of the compartment so TAU13 is transferred 1 hour into the pathway. The transfer to SOIL SURFACE marks the end of APPLICATON, 2 hours into the pathway. The sludge has now been incorporated into the soil, and the associated pathogens are being affected by soil conditions. Some sludge would be left on the equipment used to spread and incorporate the sludge and to plant the crop. Transfer of this residue also occurs at the end of compartment activities, 2 hours into the pathway.

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The user may control the amount of sludge transferred to RESIDUE and PARTICULATES by specifying values for the variables WTRES2 and WTPAR3 in the input variable P-array. The number of pathogens associated with the weight of sludge transferred is calculated by dividing the weight of sludge transferred by the total weight of sludge in the compartment from which the transfer is being made and then multiplying the number of pathogens in that compartment. All weights considered in transfers are dry weights since the moisture content of sludge or soil may differ in individual pathway runs. Calculations of transfers can always be found in the subroutine for the compartment from which a transfer is made.

Time of first transfer into compartment - Start of pathway.

Time of last transfer out of compartment - 2 hours into pathway.

Process function - RHO1
Activated: Start of pathway.
Duration: 2 hours.
Rates: Salmonella: 0.0*N(1)/hour.
Ascaris: 0.0*N(1)/hour.
Poliovirus: 0.0*N(1)/hour.

Transfers into compartment -
TAU01 = ASCIN, Transfer occurs at the start of the pathway.

Transfers out of compartment -
TAU12 = (WTRES2/(APRATE - WTPAR3))*N(1), Transfer occurs 2 hours into pathway.
TAU13 = (WTPAR3/APRATE)*N(1), Transfer occurs 1 hour into pathway.
TAU15 = N(1) - TAU12, Transfer occurs 2 hours into pathway.

Compartment 2, RESIDUE ON EQUIPMENT --

RESIDUE is left on equipment at the end of the APPLICATION compartment. The amount is determined by the variable WTRES2. The default value for this variable is an estimate. The material in the RESIDUE compartment is assumed to dry out rapidly. The process functions assigned to this and other RESIDUE compartments reflect the effects of desiccation on the model pathogens.

Time of first transfer into compartment - 2 hours into pathway.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process Function - RHO2
Activated: 2 hours into pathway.
Duration: Until all pathogens are depleted or the pathway ends.
Rates: Salmonella: -0.46*N(2)/hour. (8)
The inactivation of residue-associated salmonella is asssumed to occur at the

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rate for salmonella in drying sludge at greater than 80 percent solids.
Ascaris: -0.25*N(2)/hour. (22, 40, 74)
Poliovirus: -0.38*N(2)/hour. (88, 97)

Transfers into compartment -
TAU12 = (WTRES2/(APRATE-WTPAR3))*N(1), Transfer occurs 2 hours into pathway.

Transfers out of compartment - None.

Compartment 3, PARTICULATES --

The activities described for Compartment 1 will generate airborne dust, or PARTICULATES. It is assumed in all PARTICULATES compartments that the dust is generated at the start of activities in the compartment from which the transfer to PARTICULATES is made, in this case Compartment 1 - APPLICATION, and that the dust and its associated pathogens remain at the initial concentration until the generating activity ceases. The process functions in all PARTICULATES compartments are delayed to allow for maximum inhalation of pathogens during generation activities.

The user may specify the amount of sludge being transferred to this compartment by assigning a value to WTPAR3. There are two compartments described by the title PARTICULATES in this pathway: Compartment 3 and Compartment 4. To avoid confusion in this and other pathways a naming system was used in which the "weight transferred to PARTICULATES" is abbreviated "WTPAR" and the number of the compartent concerned is appended. Thus WTPAR3 is the weight of sludge transferred to PARTICULATES in Compartment 3.

The default value assigned WTPAR3 was determined by assuming that PARTICULATES are generated to a level of 15 mg/m^3 in a volume extending 10 meters over the 1-hectare field. The concentration of particles and the height of the volume considered are the same in all PARTICULATES compartments but the area under the dust cloud differs between pathways.

The process functions for PARTICULATES are the same as for RESIDUE and reflect the effects of rapid desiccation of the airborne material and the pathogens associated with it.

Time of first transfer into compartment - 1 hour into pathway.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RHO3
Activated: 2 hours into pathway.
Duration: Until all pathogens are depleted or the pathway ends.
Rates: Salmonella: -0.46*N(3)/hour. (8)

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Ascaris: -0.25*N(3)/hour. (22, 40, 74)
Poliovirus: -0.38*N(3)/hour. (88, 97)

Transfers into compartment -
TAU13 = (WTPAR3/APRATE)*N(1), Transfer occurs 1 hour into pathway.

Transfers out of compartment - None.

Compartment 4, PARTICULATES --

This compartment simulates the effects of a windstorm. Dust is blown up from the SOIL SURFACE (TAU54); the amount can be specified by assigning a value to WTPAR4. The default value for this variable assumes 15 milligrams of sludge-fertilized soil per cubic meter of air in a 10-meter high volume above the 1-hectare field. The time of the storm can also be controlled. The variable TWIND may be assigned a value which places the storm at any time between 50 days into the pathway and the time of harvest (THARV). TWIND may also be used to exclude a windstorm from pathway occurrences. This is done by assigning the value -2. to the variable.

Process functions for this compartment are delayed 1 hour after generation. The rates of inactivation simulate rapid drying.

Time of first transfer into compartment - TWIND.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RHO4
Activated: TWIND + 1 hour
Duration: Until all pathogens are depleted or the pathway ends.
Rates: Salmonella: -0.46*N(4)/hour. (8)
Ascaris: -0.25*N(4)/hour. (22, 40, 74)
Poliovirus: -0.38*N(4)/hour. (88, 97)

Transfers into compartment -
TAU54 = (WTPAR4/(APRATE - WTPAR3 - WTRES2))*N(5), Transfer occurs at TWIND.

Transfers out of compartment - None.

Compartment 5, SOIL SURFACE --

The first 10 centimeters of soil are the SOIL SURFACE. The soil in this compartment is subjected to a weekly moisture cycle which begins 2 hours into the pathway with the first irrigation of the field. The soil is at field capacity (20 percent weight/weight) after each irrigation and dries to the wilting point (4 percent weight/weight) between irrigations. Pathogen process functions are tied to the irrigation cycle. The rate of growth or inactivation of pathogens is dependent on the ambient temperature

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of the environment and on the available water. The ambient temperature is constant throughout the pathway and is set by the variable TEMP. The available water is a function of the time elapsed since the last irrigation.

Sludge fertilizer and pathogens are first transferred into this compartment from the APPLICATION compartment by TAU15. As the pathway progresses there are several other transfers into this compartment. At irrigation, water from Compartment 12, IRRIGATION WATER, is transferred to Compartment 9, SOIL SURFACE WATER. This water then percolates into the soil, transferring pathogens to SOIL SURFACE by TAU95. The pathogens involved in this transfer may be either soil pathogens which become suspended in the water during irrigation, a phenomenon simulated by TAU59, or pathogens introduced with the irrigation water itself. In a similar manner, after pathogens have been transferred to CROP SURFACE, some will be returned to SOIL SURFACE when gravity and wind cause dust on above-ground crops to fall to the ground (TAU75). If the field is cultivated after planting, pathogens which have been carried to SUBSURFACE SOIL (Compartment 8) will be transferred to the SOIL SURFACE as the ground is turned. This is simulated by TAU85.

There is one other way for pathogens to enter this compartment. The user may place an initial pathogen population in any pathway compartment by specifying the compartment number and the desired population in the POPL variable of the $ARGS name list. The mechanism for handling variable specification is fully described in the user's manual for the program (Appendix A). Specifying an initial pathogen population allows the user to examine the effects of several sludge applications. The final compartment populations of one model run would be input as initial populations in the next run. Environmental conditions may be unique for each run, or standard default values may be used.

Pathogens are transferred from this compartment into Compartment 4, PARTICULATES, by TAU54; Compartment 8, SUBSURFACE SOIL, by TAU58; Compartment 7, CROP SURFACE, by TAU57; Compartment 9, SOIL SURFACE WATER, by TAU59; Compartment 6, DIRECT REMOVAL, by TAU56; and to SURFACE RUNOFF by TAU50. PARTICULATES are generated by a windstorm that occurs at a user-specifiable time, TWIND. A further description of the windstorm is found in the preceding description of Compartment 4. The transfer from SOIL SURFACE to SUBSURFACE SOIL occurs after each irrigation as irrigation water percolates below the 10-centimeter mark which separates SOIL SURFACE from SUBSURFACE SOIL. The time of this transfer is controlled by the infiltration rate of SOIL SURFACE WATER, a parameter the user may specify in variable FILTR8. The transfer of soil and soil pathogens to CROP SURFACE is different for each type of crop. As explained in the General Considerations for this pathway, above-ground crops are dusted with soil during the arbitrary windstorm, while on-ground and below-ground crops would not be involved in this transfer. At harvest, time THARV, all three types of crops will be contaminated with soil. The fraction of the total pathogen population in Compartment 5 which is transferred to the designated crops is specified in the variables FCROP1, FCROP2, and FCROP3.

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Since only one crop is grown in the field during a particular model run, the user must be careful in this pathway to match specified variables to crop type. Inputting a user-specified value in position 16 of the P-array when running this pathway for CROP = 0.0 (on-ground crop type) will result in the use of the default value for FCROP2 in TAU57. Position 16 is FCROP1, a variable only used when CROP = +1. The user would have to specify the value in position 17 to make a change when looking at on-ground crops. The linking of variables occurs for many parameters.

Soil and soil pathogens are suspended in irrigation water while it is lying on the surface of the field and is considered in Compartment 9, SOIL SURFACE WATER. This soil and and its associated pathogens would return to SOIL SURFACE as the irrigation water percolates into the ground. Workers will enter the field periodically and will carry dirt away with them. This DIRECT REMOVAL is a weekly event until harvest. Two variables (WTDRM and WTDRMH) control the amount of soil and pathogens transferred to DIRECT REMOVAL because it is assumed that more soil is removed during harvest than during inspection.

The transfer to SURFACE RUNOFF simulates the effects of a rain and occurs at TRAIN. SURFACE RUNOFF is not a compartment because the scope of this model is not large enough to follow pathogens beyond the 1 hectare which constitutes the planted field. RUNOFF by definition leaves the field. The rain which produces runoff is an arbitrary event which does not occur under default conditions. The user must set TRAIN to a positive number. The user may control the number of pathogens removed from the pathway by TAU50 by specifying the value of FRRAIN.

Time of first transfer into compartment - 2 hours into pathway.

Time of last transfer out of compartment - THARV.

Process function - RHO5
Activated: 2 hours into the pathway
Duration: Until the end of the pathway.
Rates: Salmonella: 0.070*N(5)/hour, for $20 < TEMP < 45$ and $0 < TIRRG \leq 3.5$ days. The growth of salmonella is assumed to occur at one-half the rate for E.coli in sterile compost. (62)
-0.012*N(5)/hour, for $20 \leq TEMP < 45$ and $3.5 < TIRRG \leq 5.5$ days. (23, 72, 73)
-0.46*N(5)/hour, for TEMP < 45 and $5.5 < TIRRG < 7$ days. (8)
-3.45*N(5)/hour, for $TEMP \geq 45$ and any time. (8, 93)
0.0*N(5)/hour, for TEMP < 20 and any time. No changes in pathogen population are assumed for temperatures less than 20°C.

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Ascaris:
-0.0005*N(5)/hour, for TEMP < 40 and 8 hours < TIRRG ≤ 5.5 days. (83)
-1.54*N(5)/hour, for 40 ≤ TEMP ≤ 50 and 8 hours < TIRRG ≤ 5.5 days. (7, 78)
-0.25*N(5)/hour, for TIRRG > 5.5 days and any temperature. (22, 40, 74)

Poliovirus:
-0.005*N(5)/hour, for 15 < TEMP < 45 and 8 hours < TIRRG ≤ 6.5 days. (27, 96)
-0.027*N(5)/hour, for TEMP < 45 and TIRRG > 6.5 days. (87, 96)
-0.38*N(5)/hour, for TEMP ≥ 45 and any time. (88, 97)
-0.00087*N(5)/hour, for TEMP < 15 and 8 hours < TIRRG < 6.5 days. (96)

Transfers into compartment -
TAU15 = N(1) - TAU12, Transfer occurs 2 hours into pathway.
TAU75(above-ground crop) = 0.0017*N(7).
TAU75(other crops) = 0.0*N(7), Transfers begin at TWIND and continue for 5 days.
TAU85 = FRSUR*N(8), Transfer occurs at 2 week intervals if FRSUR > 0 and cultivation takes place.
TAU95 = N(9) - TAU97, Transfer occurs at TIRRG + DEPTH/FILTR8 for each irrigation.

9-1/8"

Transfers out of compartment -
TAU50 = FRRAIN*N(5), Transfer occurs only if there is a rain and then at the time of rain, TRAIN.
TAU54 = (WTPAR4/(APRATE - WTRES2 - WTPAR3))*N(5), Transfer occurs at TWIND.
TAU56(before harvest) = (WTDRM/(APRATE - WTPAR3 - WTRES2)), Transfer occurs 4 hours into the pathway and then at weekly intervals until THARV.
TAU56(harvest) = (WTDRMH/(APRATE - WTRES2 - WTPAR3))*N(5), Transfer occurs at THARV.
TAU57(above-ground crop) = FCROP1*N(5), Transfer occurs at TIRRG (transferred during each irrigation).
TAU57 (on-ground crop) = FCROP2*N(5),
TAU57(below-ground crop) = FCROP3*N(5), Transfer occurs at THARV.
TAU58 = SUBSOL*N(5), Transfer occurs at TIRRG + DEPTH/FILTR8 (transferred during each irrigation).
TAU59 = SUSPND*N(5), Transfer occurs at TIRRG (transferred during each irrigation) and at TRAIN.

Compartment 6, DIRECT REMOVAL --

Surface soil and the pathogens associated with it will adhere to the shoes, clothing, and skin of people who enter the field. These pathogens are directly removed from the field. Two variables determining the weight of soil transferred from SOIL SURFACE to DIRECT REMOVAL have been defined. One, designated WTDRM, determines the weight transferred to workers in the

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field supervising irrigation. This variable is used in TAU56 at 4 hours into the pathway and then weekly until the time of harvest (which is determined by the variable THARV). The other variable WTDRMH is used in TAU56 at the time of harvest. The default value for WTDRMH is larger than the default value for WTDRM. This larger value was chosen to reflect the greater possible contact with soil during harvest.

Time of first transfer into compartment - 4 hours into pathway.

Time of last last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted following the last transfer into the compartment.

Process function - RHO6
  Activated: 4 hours into pathway then at weekly intervals until harvest (THARV) and at harvest.
  Duration: 24 hours after each transfer.
  Rates: Salmonella: N(6) = 0.0 after 24 hours.
  Ascaris: N(6) = 0.0 after 24 hours.
  Poliovirus: N(6) = 0.0 after 24 hours.

Transfers into compartment -
  TAU56(before harvest) = (WTDRM/(APRATE - WTRES2 - WTPAR3))*N(5), Transfer occurs 4 hours into the pathway and then at weekly intervals until THARV.
  TAU56(harvest) = (WTDRMH/(APRATE - WTRES2 - WTPAR3))*N(5), Transfer occurs at THARV.

Transfers out of compartment - None.

Compartment 7, CROP SURFACE --
Before each pathway run the user must specify one crop type. The default value for the variable CROP specifies the above-ground type represented by bush tomatoes. An on-ground crop represented by zucchini squash and a below-ground crop represented by carrots are the other choices. The crop types are described in the General Considerations for this pathway (items e and g). Table 4c presents a convenient summary of the parameters defining each crop.

The type of crop controls the transfers into and out of this compartment. Above-ground crops contact pathogens in dust generated from the SOIL SURFACE, a transfer modeled by TAU57 which occurs at TWIND; and from SOIL SURFACE WATER which splashes up during irrigation, a transfer modeled by TAU97. On-ground crops are not affected by blown dust since they are essentially at equilibrium with surface soil but the transfer from SOIL SURFACE WATER is greater than for above-ground crops. On-ground crops are covered by irrigation water during each irrigation. Below-ground crops lie half in the surface soil and half in the subsurface soil. No dust or irrigation water reaches them. All three crops contact pathogens transferred from SOIL SURFACE by TAU57 at harvest. This represents the normal

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TABLE 4c. CROP PARAMETERS

TYPE	GROWTH PERIOD (days)	DISTANCE BETWEEN PLANTS (m)	DISTANCE BETWEEN ROWS (m)	YIELD (kg/100m)	SIZE	WEIGHT (kg)
Above-ground Tomatoes	60-80	0.6	1.5	224	Sphere 10 cm diameter	0.23
On-ground Zucchini Squash	60	0.5	1	150	Cylinder 20 cm length 5 cm diameter	0.23
Below-ground Carrots	70-75	0.5	0.5	112	Cylinder 20 cm length 2.5 cm diameter	0.10

dirt found on all fresh vegetables. Only below-ground crops also receive a transfer from SUBSURFACE SOIL by TAU87.

Time of first transfer into compartment - TIRRG.

Time of last transfer out of compartment - THARV.

Process function - RH07
Activated: TIRRG.
Duration: Until THARV.
Rates:
Salmonella: -0.096*N(7)/hour, for above-ground and on-ground crops. (72, 73)
0.0*N(7)/hour, for below-ground crops.
Ascaris: -1.54*N(7)/hour, for above-ground and on-ground crops. (7, 78)
0.0*N(7)/hour, for below-ground crops.
Poliovirus: -0.069*N(7)/hour, for above-ground and on-ground crops. (49)
0.0*N(7)/hour, for below-ground crops.

Transfers into compartment -
TAU57(above-ground crop) = FCROP1*N(5). Transfer occurs at TWIND and at THARV.
TAU57(on-ground crop) = FCROP2*N(5),
TAU57(below-ground crop) = FCROP3*N(5), Transfers occur at THARV.
TAU87 = (FCROP3*N(8))/5., Transfer occurs at THARV for below-ground crops.
TAU97(above-ground crop) = FSUR1*N(9),
TAU97(on-ground crop) = FSUR2*N(9),
TAU97(below-ground crop) = FSUR3*N(9), Transfers occur at TIRRG (transferred during each irrigation).

Transfers out of compartment -
TAU75(above-ground crop) = 0.0017*N(7),
TAU75(other crops) = 0.0*N(7), Transfers begin at TWIND and continue for 5 days.
TAU79 = N(7), Transfer occurs only if CROP = 0.0 (on-ground) and then at each TIRRG after day 50 (the time when crops are present).
TAU710 = N(7), Transfer occurs at THARV.

Compartment 8, SUBSURFACE SOIL --

This compartment represents the soil from 10 to 60 centimeters below the surface. This SUBSURFACE SOIL is at constant moisture (field capacity, 20 percent weight/weight) and temperature (15°C). Pathogens from the sludge-fertilized upper 10 centimeters of soil are transferred into this compartment with percolating irrigation water. The fraction of the total SOIL SURFACE (Compartment 5) pathogen population transferred is determined by the variable SUBSOL. The time of the transfer by TAU58 is controlled by the depth of irrigation water which must soak in (DEPTH) and the rate of water infiltration (FILTR8), but the transfer occurs after each irrigation.

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There are four possible transfers out of this compartment. Pathogens may be transferred to Compartment 11, GROUNDWATER, by TAU811. The variable, FRGRND, which specifies the fraction of total SUBSURFACE SOIL pathogens transferred, is set to zero under default conditions. The 6 centimeters of applied irrigation water specified by default values would only penetrate to 60 centimeters, precluding transfer to GROUNDWATER. The user should specify a value for FRGRND if DEPTH is set to more than 6 centimeters.

Pathogens may be transferred to Compartment 5, SOIL SURFACE, by TAU85 if the user specifies a positive value for the variable FRSUR. This variable indicates that cultivation is to be simulated and sets the fraction of transfer. Cultivation, once flagged, occurs at 2-week intervals from the start of the pathway.

Pathogens may be transferred to Compartment 7, CROP SURFACE, by TAU87 if the below-ground crop type is being modeled. This transfer would occur at harvest.

Pathogens which did not transfer out of this compartment in the three transfers listed above become part of the SOIL SINK at harvest. The SOIL SINK is not defined as a compartment in this model.

Time of first transfer into compartment - TIRRG + (DEPTH/FILTR8).

9-1/8"

Time of last transfer out of compartment - THARV.

Process function - RHO8
  Activated: TIRRG + (DEPTH/FILTR8).
  Duration: Until THARV.
  Rates:
    Salmonella: -0.012*N(8)/hour. (23, 72, 73)
    Ascaris: -0.00053*N(8)/hour. (83)
    Poliovirus: -0.0049*N(8)/hour. (27, 96)

Transfers into compartment -
  TAU58 = SUBSOL*N(5), Transfer occurs at TIRRG + DEPTH/FILTR8 (transferred during each irrigation).

Transfers out of compartment -
  TAU80 = N(8) - TAU811, Transfer occurs at THARV.
  TAU85 = FRSUR*N(8), Transfer occurs at 2 week intervals if FRSUR > 0 and cultivation takes place.
  TAU87 = (FCROP3*N(8))/5., Transfer occurs at THARV for below-ground crops.
  TAU811 = FRGRND*N(8), Transfer occurs at TIRRG + 1 hour then weekly until THARV and also at TRAIN.

Compartment 9, SOIL SURFACE WATER --
Irrigation in this model involves flooding the field with water to a uniform depth (specified by the variable DEPTH) and then allowing the water to infiltrate the soil at a constant rate (specified by the variable

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FILTR8). The water transfers into SOIL SURFACE WATER from Compartment 12, IRRIGATION WATER, by TAU129 and may carry with it a pathogen load. Pathogens in SOIL SURFACE and on the CROP SURFACE of on-ground crops will become suspended in the overlying water. These transfers from Compartment 5 and Compartment 7, respectively, will occur for each TIRRG.

The variable TIRRG is used in several ways in the model. Its value is incremented by 168 hours each time it is used so that irrigation occurs at weekly intervals after the first irrigation (2 hours into the pathway). The variable is also used in the process functions for Compartment 5 to keep track of the time elapsed since the last irrigation.

Pathogens transfer back to Compartment 5, SOIL SURFACE, and Compartment 7, CROP SURFACE, when the irrigation water soaks into the soil. Although this would normally be a gradual process, TAU95 and TAU97 occur at the end of each irrigation, as a single transfer to each compartment.

Time of first transfer into compartment - 2 hours into pathway at the first irrigation.

6-1/2"

Time of last transfer out of compartment - Transfers are made from this compartment following each irrigation. The last transfer will follow the last irrigation before harvest. The exact time depends on the value of THARV.

9-1/8"

Process function - RH09
    Activated: TIRRG (with each irrigation).
    Duration: TIRRG + (DEPTH/FILTR8).
    Rates: Salmonella: 0.23*N(9)/hour. A 3-hour generation time is assumed for growth of salmonella suspended in irrigation water.
        Ascaris: 0.0*N(9)/hour.
        Poliovirus: 0.0*N(9)/hour. No change is assumed for ascaris and poliovirus suspended in irrigation water.

Transfers into compartment -
    TAU59 = SUSPND + N(5), Transfer occurs at TIRRG (transferred during each weekly irrigation) and at TRAIN.
    TAU79 = N(7), Transfer occurs only if CROP = 0.0(on-ground) and then at each TIRRG after day 50 (the time when crops are present).
    TAU129 = N(12), Transfer occurs at each TIRRG.

Transfers out of compartment -
    TAU95 = N(9) - TAU97, Transfer occurs at TIRRG + DEPTH/FILTR8 for each TIRRG.
    TAU97 (on-ground crop) = FSUR2*N(9).
    TAU97 (below-ground crop) = FSUR3*N(9), Transfers occur at TIRRG, (transferred during each irrigation).

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Compartment 10, HARVESTING AND PREPARATION --

This compartment was originally designed to simulate harvesting of the crop and those processes which are often a part of handling raw vegetables, such as storage and washing. These processes are now included in vegetable-exposure risk calculations discussed in Section 6. No process functions are defined. Pathogens are transferred into this compartment from Compartment 7, CROP SURFACE, by TAU710. The transfer represents the physical removal of mature crops from the field, or harvest. This occurs at the user-specified time of harvest, THARV. Pathogens are transferred out of the compartment after 24 hours. The duration of the compartment simulates the time necessary to hand-pick a 1-hectare plot.

Time of first transfer into compartment - THARV.

Time of last transfer out of compartment - THARV + 24 hours.

Process function - RH010
  Activated: THARV.
  Duration: 24 hours.
  Rates: Salmonella: 0.0*N(10)/hour.
    Ascaris: 0.0*N(10)/hour.
    Poliovirus: 0.0*N(10)/hour.

Transfers into compartment -
  TAU710 = N(7), Transfer occurs at THARV.

Transfers out of compartment -
  TA1013 = N(10), Transfer occurs at THARV + 24 hours.

Compartment 11, GROUNDWATER --

Pathogens applied to a field may contaminate groundwaters if surface water percolates deeply enough. The default values incorporated into the model preclude such contamination but, as explained in Compartment 8, the user may specify a transfer of pathogens to GROUNDWATER in order to model the effects of heavy irrigation.

Pathogens transferred to GROUNDWATER would be inactivated slowly as shown in the process functions listed below. Pathogens would also be dispersed throughout the aquifer. The user may determine the effects of dispersion by specifying a value for DILGRN. This variable is included in the equation for TA1112 and affects the pathogen number transferred to Compartment 12, IRRIGATION WATER. Another variable in the equation for TA1112 is DILIRR. It determines what fraction of the water used for irrigation is from GROUNDWATER by specifying the fraction of the pathogens present that will be transferred. The default values for these variables were not chosen to model any particular situation. One-half of the water in Compartment 12 is from GROUNDWATER, while the aquifer dilutes incoming percolation by 1 x 10^6 when default values are used.

Time of first transfer into compartment - TIRRG + 1 hour or TRAIN, whichever occurs first.

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Time of last transfer out of compartment - Transfers are made from this compartment before each irrigation. The last transfer will occur just before the last irrigation to precede harvest. The exact time depends on the value of THARV.

Process function - RH011
    Activated: At the time of first transfer in.
    Duration: Until end of pathway.
    Rates: Salmonella: -0.012*N(11)/hour. (23, 72, 73)
        Ascaris: -0.00053*N(11)/hour. (83)
        Poliovirus: -0.012*N(11)/hour. (95)

Transfers into compartment -
    TAU811 = FRGRND*N(8), Transfer occurs at TIRRG + 1 hour, then weekly until THARV and also at TRAIN.

Transfers out of compartment -
    TA1112 = DILIRR*DILGRN*N(11), Transfer occurs 1 hour into pathway and then at weekly intervals.

6-1/2"

Compartment 12, IRRIGATION WATER --

In this compartment, water from two sources is combined. Water is transferred into the compartment from GROUNDWATER by TA1112 and from an EXTERNAL SOURCE by TAU012. GROUNDWATER represents well water used here for irrigation. It may contain pathogens which have been carried through SUBSURFACE SOIL by deep percolation (TAU811). EXTERNAL SOURCE represents surface flows used for irrigation. This water may also contain pathogens. The user may specify the level of contamination by assigning a value to the variable COUNT. The ratio of GROUNDWATER to EXTERNAL SOURCE water is determined by the variable DILIRR.

EXTERNAL SOURCE is not defined as a pathway compartment since the scope of the model does not consider water pollution other than the possible additive effects of using contaminated water on a sludge-fertilized field. The IRRIGATION WATER compartment has a very short duration and no process functions have been defined. The compartment does not represent a physical part of the environment but rather the transition between several states. As soon as the waters are mixed they become SOIL SURFACE WATER, represented by Compartment 9. This transfer is accomplished by TAU129 at weekly intervals.

Time of first transfer into compartment - 1 hour into pathway.

Time of last transfer out of compartment - Transfers are made from this compartment for each irrigation. The last transfer will occur for the last irrigation before harvest. The exact time depends on the value of THARV.

Process function - RH012
    Activated: 1 hour into pathway.
    Duration: 1 hour.

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Rates: Salmonella: 0.0*N(12)/hour.
Ascaris: 0.0*N(12)/hour.
Poliovirus: 0.0*N(12)/hour.

Transfers into compartment -
TAU012 = COUNT, Transfer occurs 1 hour into pathway and then at weekly intervals.
TA1112 = DILIRR*DILGRN*N(11), Transfer occurs 1 hour into pathway and then at weekly intervals.

Transfers out of compartment -
TAU129 = N(12), Transfer occurs at each TIRRG.

Compartment 13, COMMERCIAL CROP --

This compartment exists to provide for the calculations necessary to determine the number of pathogens per crop unit of harvested vegetables. This number is output in position 30 of the Pathway 4 P-array. This is the number which is used by the vegetable-exposure risk calculations.

Significant calculations - The number of pathogens per crop unit (FPCU) equals:
N(13)/53191, for above-ground crops.
N(13)/48000, for on-ground crops.
N(13)/196800, for below-ground crops.

9-1/8"

A crop unit is one tomato, zucchini, or carrot. The number in the numerator of the fractions listed above is the number of crop units which would be grown in the 1-hectare field when the assumptions as to size and plant spacing listed in Table 4c are followed.

Time of first transfer into compartment - THARV + 24 hours.

Time of last transfer out of compartment - There are no transfers out of this compartment, which is the last in the pathway. Consideration of the compartment ends when the pathway terminates.

Process function - RH013
Activated: THARV + 24 hours.
Duration: 1 hour.
Rates: Salmonella: 0.0*N(13)/hour.
Ascaris: 0.0*N(13)/hour.
Poliovirus: 0.0*N(13)/hour.

No process functions are defined for this compartment. The compartment was originally designed to simulate the effects of commercial food processes on pathogens. These processes are now part of the vegetable-exposure risk calculation.

Transfers into compartment -
TA1013 = N(10), Transfer occurs at THARV + 24 hours.

Transfers out of compartment - None.

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PATHWAY 5 - SLUDGE APPLICATION PATHWAY - FERTILIZER FOR PASTURE CROPS

General Considerations

This pathway describes the fate of sewage sludge pathogens after the application of raw or anaerobically digested sludge to a 1-hectare pasture planted in a forage crop, such as alfalfa or fescue, and grazed by cattle at the time of application. Figure 5 shows the process compartments and transfers which define this application regime. The differential equations which describe this pathway are presented in Table 5a. Each process function and transfer function is defined in the following section. Table 5b lists the definitions of and the default values for the input variables used to define environmental factors. The general considerations and assumptions discussed below were made to facilitate model development.

a. The pathway will run for one 30-day month. It is possible to look at a longer period of time by using the final pathogen counts in each compartment as the initial conditions of each compartment in a subsequent run. This is done by specifying each compartment number and the desired pathogen population for each compartment in the POPL variable of the $ARGS name list. The mechanism for setting initial pathogen populations is described in the user's manual for the program (Appendix A).

b. The ambient temperature of the environment is specified for each model run by the variable TEMP and remains constant throughout a run. The default ambient temperature is 20°C.

c The amount of sludge applied to the pasture (APRATE) and the concentration of pathogens in that sludge (ASCRS) are user-specifiable variables. The default values are based on adding 5607 kilograms of sludge to each hectare of land each month (the equivalent of 30 tons of sludge per acre per year) (48). The default values for the number of pathogens in applied sludge reflect a conservative "worst case" by being equal to the concentration of each pathogen in raw sludge (1, 4, 28, 32, 77). The value of output variable PTOTL in position 20 of Pathway 1's (General Sludge Treatment Pathway) P-array is equal to the number of pathogens per kilogram of sludge at the end of general sludge treatment. The user may run Pathway 1 for one of the three pathogens using variable values which approximate conditions at a particular treatment facility and then use the output value of PTOTL as the input value for ASCRS in this pathway. In this way a treatment and an application pathway may be linked and a selected pathogen followed from sewage influent to consumer.

d. For convenience the pasture is assumed to be 1 hectare in size. This area is large enough to support 12 cows (46) which take their entire intake of food from the forage crop growing in the pasture.

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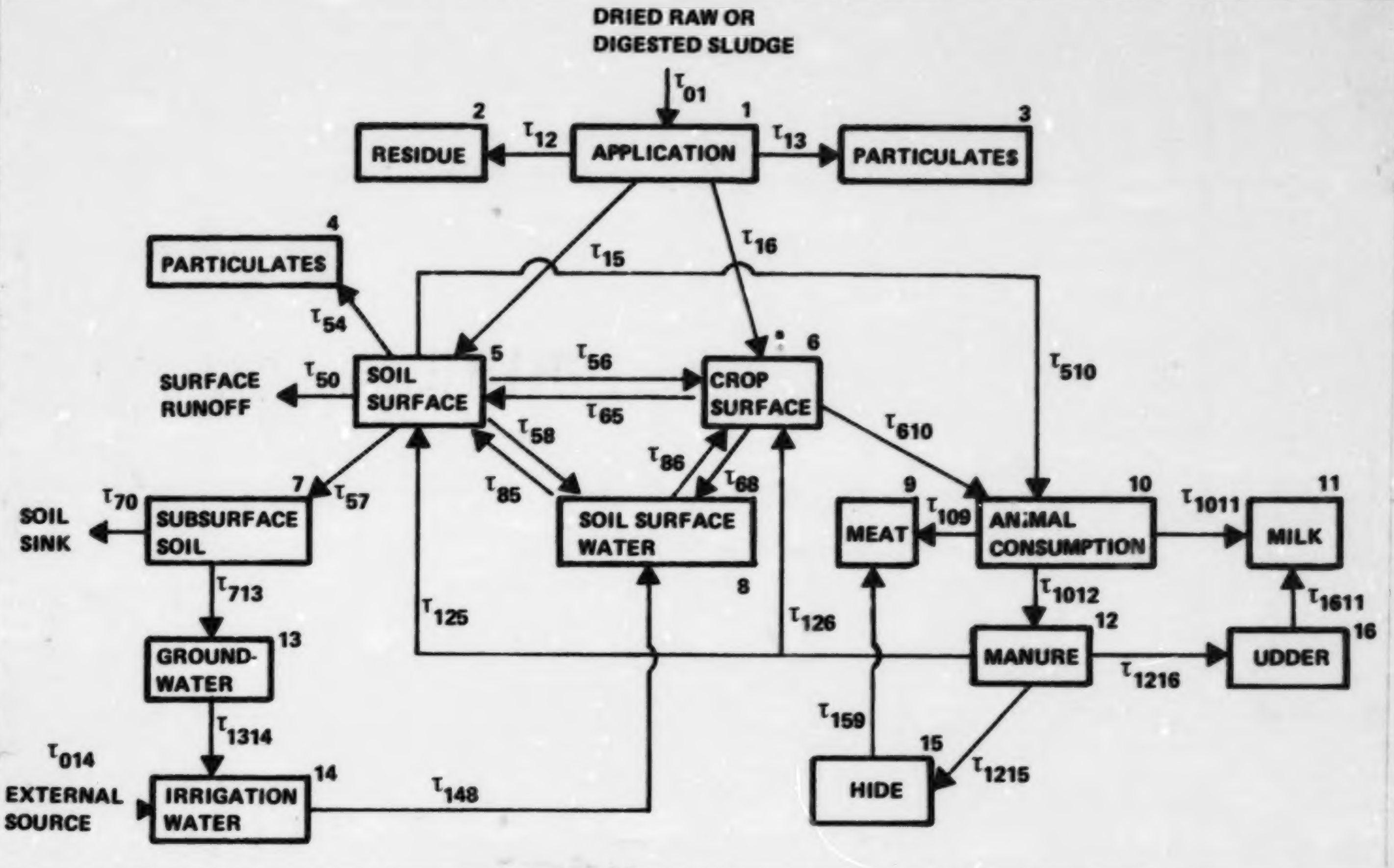
DRIED RAW OR DIGESTED SLUDGE
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APPLICATION
τ_{12}
2
RESIDUE
τ_{13}
3
PARTICULATES
τ_{15}
τ_{16}
4
PARTICULATES
τ_{54}
5
SOIL SURFACE
τ_{50}
SURFACE RUNOFF
τ_{56}
τ_{65}
6
CROP SURFACE
τ_{510}
τ_{610}
τ_{58}
τ_{85}
τ_{86}
τ_{68}
7
τ_{57}
τ_{70}
SOIL SINK
SUBSURFACE SOIL
8
SOIL SURFACE WATER
9
MEAT
τ_{109}
10
ANIMAL CONSUMPTION
τ_{1011}
11
MILK
τ_{713}
13
GROUND-WATER
τ_{125}
τ_{126}
τ_{1012}
12
MANURE
τ_{1611}
16
UDDER
τ_{1216}
τ_{1314}
τ_{159}
15
HIDE
τ_{1215}
τ_{014}
EXTERNAL SOURCE
14
IRRIGATION WATER
τ_{148}

Figure 5. Sludge Application Pathway - Fertilizer for Pasture Crops

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TABLE 5a. DIFFERENTIAL EQUATIONS FOR PATHWAY 5

SLUDGE APPLICATION PATHWAY - FERTILIZER FOR PASTURE CROPS

$$\dot{N}_1 = \tau_{01} - \tau_{12} - \tau_{13} - \tau_{15} - \tau_{16} + \rho_1$$

$$\dot{N}_2 = \tau_{12} + \rho_2$$

$$\dot{N}_3 = \tau_{13} + \rho_3$$

$$\dot{N}_4 = \tau_{54} + \rho_4$$

$$\dot{N}_5 = \tau_{15} + \tau_{65} + \tau_{85} + \tau_{125} - \tau_{50} - \tau_{54} - \tau_{56} - \tau_{57} - \tau_{58} - \tau_{510} + \rho_5$$

$$\dot{N}_6 = \tau_{16} + \tau_{56} + \tau_{86} + \tau_{126} - \tau_{65} - \tau_{68} - \tau_{610} + \rho_6$$

$$\dot{N}_7 = \tau_{57} - \tau_{70} - \tau_{713} + \rho_7$$

$$\dot{N}_8 = \tau_{58} + \tau_{68} + \tau_{148} - \tau_{85} - \tau_{86} + \rho_8$$

$$\dot{N}_9 = \tau_{109} + \tau_{159} + \rho_9$$

$$\dot{N}_{10} = \tau_{510} + \tau_{610} - \tau_{109} - \tau_{1011} - \tau_{1012} + \rho_{10}$$

$$\dot{N}_{11} = \tau_{1011} + \tau_{1611} + \rho_{11}$$

$$\dot{N}_{12} = \tau_{1012} - \tau_{125} - \tau_{126} - \tau_{1215} - \tau_{1216} + \rho_{12}$$

$$\dot{N}_{13} = \tau_{713} - \tau_{1314} + \rho_{13}$$

$$\dot{N}_{14} = \tau_{014} + \tau_{1314} - \tau_{148} + \rho_{14}$$

$$\dot{N}_{15} = \tau_{1215} - \tau_{159} + \rho_{15}$$

$$\dot{N}_{16} = \tau_{1216} - \tau_{1611} + \rho_{16}$$

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TABLE 5b. VARIABLES FOR PATHWAY 5

SLUDGE APPLICATION PATHWAY - FERTILIZER FOR PASTURE CROPS

POSITION	DEFAULT VALUE	VARIABLE	DEFINITION
		INPUT VARIABLES	
1	1.95E+7 4.95E+2 6.52E+7	ASCRS	Number pathogens per kilogram of applied sludge.
2	5.607E+3	APRATE	Application rate of sludge in kilograms per hectare.
3	APRATE*ASCRS	ASCIN	Total number of pathogens entering pathway. If present, overrides first two variables.
4	10.	WTRES2	Dry weight in kilograms of sludge left as residue on equipment used for Application.
5	15.	WTPAR3	Dry weight in kilograms of particulates generated by sludge application.
6	0.7	ASLSUR	Fraction of transfer from Application to Soil Surface.
7	20.	TEMP	Ambient temperature throughout the pathway in degrees Celsius.
8	-2.	TRAIN	Time in hours of arbitrary rain. (If -2., there is no rain.)
9	0.017 0.0085 0.017	FRAIN	Fraction of total pathogens transferred from Soil Surface to Surface Runoff by rain.
10	0.1 0.05 0.1	SSTSSW	Fraction of transfer from Soil Surface to Soil Surface Water.
11	0.001 0.0 0.83	SSTSSS	Fraction of transfer from Soil Surface to Subsurface Soil.

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TABLE 5b. (continued)

POSITION	DEFAULT VALUE	VARIABLE	DEFINITION
12	6.	DEPTH	Depth of irrigation water in centimeters.
13	2.	FILTR8	Infiltration rate of Soil Surface Water into soil in centimeters/hour.
14	0.1 0.05 0.1	SSWTCS	Fraction of transfer from Soil Surface Water to Crop Surface.
15	15.	WTPAR4	Dry weight in kilograms of particulates generated from Soil Surface.
16	0.01	TCSTSS	Fraction of transfer per day from Crop Surface to Soil Surface.
17	0.5	SURCRP	Weight in kilograms of soil transferred from Soil Surface to Crop Surface.
18	13.2	SCNSMP	Weight in kilograms of soil consumed by 12 cows each day.
19	0.5	CSTSSW	Fraction of transfer from Crop Surface to Soil Surface Water.
20	84.	FORAG	Weight in kilograms of dry forage consumed by 12 cows each day.
21	0.06	FSLDGE	Fraction of forage which is sludge.
22	0.001	TMHIDE	Fraction of transfer from Manure to Hide.
23	+1.	COW	Animal type: -1. = meat cow +1. = milk cow.
24	0.7	TMSSUR	Fraction of transfer from Manure to Soil Surface.

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TABLE 5b. (continued)

POSITION	**DEFAULT VALUE**	**VARIABLE**	**DEFINITION**
25	-2.	TSLOTR	Time of slaughter in days. (If -2., there is no slaughter).
26	0.1	FRSLOT	Fraction from Hide to Meat at slaughter.
27	0.05	UDRMLK	Fraction of transfer from Udder to Milk. (Cow = +1.0)
28	0.0	SSTGW	Fraction of transfer from Subsurface Soil to Groundwater.
29	1.0E-6	GNDIL	Groundwater and use dilution.
30	0.5	FRGIR	Fraction of irrigation water from Groundwater.
31	0.0	EXTRN	External Source pathogen input to irrigation water (total population).
32	0.0	DTCTMT	Fraction of transfer from Animal Consumption to Meat.
33	0.0	DTCTMK	Fraction of transfer from Animal Consumption to Milk.
		OUTPUT VARIABLES	
34	(output)	TIRRG	Time in hours after each irrigation event.

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TABLE 5b. (concluded)

NOTES: The number of pathogens per day entering the pathway will default to APRATE*ASCRS if no value is specified for ASCIN. If a value is specified for ASCIN, it will override the APRATE*ASCRS value.

Whenever three default values are specified for any variable in the list above, the order is salmonellae, ascaris, poliovirus pathogen types. The appropriate default value will be selected to agree with the pathogen type being considered in a particular run.

All units of measure are in kilograms, degrees Celsius, or hours unless otherwise stated.

Variables labeled "output" are for internal computations and are not available to the user as input.

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e. The cows are assumed to be a dairy herd, but a slaughter option has been provided to evaluate pathogen transfers to meat. Each cow consumes 7 kilograms dry weight of forage each day (65). Six percent of the cow's total consumption is crop-associated sludge (17). In addition, each cow is assumed to ingest 200-400 kilograms of soil each year or approximately 2 percent of their total diet on a wet weight basis (38). This amounts to 1.1 kilograms per animal per day. These assumptions were used in setting the default values for variables FORAG, SCNSMP, and FSLDGE. Please note that these variables have been set to account for all 12 cows. If the user intends to specify variable values in this pathway, each variable description should be read carefully to determine whether the variable accounts for 1 or 12 cows.

f. Each cow will add 10 kilograms of manure at 80 percent moisture (60, 58) to the pasture each day. This addition occurs for all 12 cows at one time to simplify the bookkeeping on manure process functions. Manure is assumed to dry at a rate which is based on sludge evaporation. Sludge evaporation rates depend on the clear water evaporation rate for a particular area (10).

g. Salmonella infections in cattle can be systemic (13). Transfers of pathogens directly from the cow to milk and meat are included in the pathway (TA1011 and TAU109, respectively). Because infections of adult cattle are usually nonsymptomatic and localized in the mesenteric lymph nodes (5), default values for the fraction of transfer directly to milk and meat (variables DTCTMK and DTCTMT, respectively) are zero for all pathogens. Infections in cattle are assumed to occur whenever the total consumption of salmonella exceeds 1×10^9 cells per day. In the event of infection, the number excreted per cow per day in manure is increased to 1×10^{12}. Cows cannot be infected by poliovirus or ascaris ova (ascaris in this model always refers to Ascaris lumbricoides); both are assumed to be unaffected by herbivore digestion and to be excreted in the same numbers as ingested. Milk and meat can be contaminated by contact with manure. All three pathogens can be transferred by this route.

h. The user must decide before each pathway run if the cattle grazing the sludge-fertilized pasture are to be a dairy herd and milked or are to be a beef herd and slaughtered for meat. If the dairy option (this is the default condition) is selected, cows are milked twice a day at 12-hour intervals. Each cow will deliver 15 liters of milk at each milking (65). The milk is stored at 4°C regardless of the ambient temperature selected for a model run. The total growth of salmonella in milk is limited to 1×10^{12} per milliliter.

i. If the beef herd option is selected by setting the variable COW to -1., a fraction of the manure which contacts hide will be transferred to meat during slaughter (91). Each cow yields 270 kilograms of meat (53).

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j. At the time of application, sludge is chain-harrowed to distribute it evenly over the pasture. A fraction of the applied sludge is knocked to the surface soil, while a fraction clings to crop surfaces. The user may specify this distribution through the variable ASLSUR. Surface soil is defined as the first 10 centimeters of soil. This zone is affected by changing temperatures and is assumed to dry after each irrigation. Below the surface soil is the subsurface soil which extends from 10 to 80 centimeters. The depth of the zone was defined to include that soil area from which 90 percent of the water requirements of a forage crop are met (6).

k. Default values for soil factors describe a sandy loam soil. The water infiltration rate (26, 23) and water holding capacity of the soil (80) are functions of soil type and determine the duration of several compartments. Values used in the transfer of pathogens from the surface to subsurface soil zones were based upon the ability of sandy loam soils to filter and adsorb particles of different sizes carrying different charges (4, 89).

l. The pasture is irrigated after sludge application and at 7-day intervals (6). The field is assumed to be flooded to a uniform depth. The water then infiltrates the soil at a uniform rate. The default depth of irrigation is calculated to allow infiltration of water only 60 to 90 centimeters below the surface (6), precluding transfer to groundwater and exhibiting good irrigation management. The pasture will be at field capacity after irrigation and the upper 10 centimeters of soil will dry out at a rate calculated for sandy loam soils in the Southwest (96). The area of the field and the irrigation regime should allow production of 7 to 10 tons of alfalfa (or similar forage) per year (3).

m. Irrigation water may be pumped from groundwater influenced by irrigation, may be from the diversion of surface flows, or may be a combination of water from both sources. Variables are included in the pathway to indicate the dilution factor (GNDIL) of pathogens present in groundwater and the fraction of the total irrigation from this source (FRGIR). The number of pathogens from an external source (EXTRN) can also be specified.

n. An optional rain is included in the pathway. If requested, the rain will produce surface runoff which removes a fraction of surface-soil-associated pathogens. The values incorporated in the model for intensity and duration of rainfall result in 1/2 inch of rain falling on the pasture in 24 hours. This produces a moderate runoff calculated as one-fourth the peak discharge for a sandy loam soil covered by grass (14).

o. Particulates generated during sludge application and by the milling of cows in the pasture are assumed to be at a level of 15 milligrams of sludge and soil per cubic meter of air in the area of the pasture and to a height of 10 meters.

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Compartment Descriptions

Compartment 1, APPLICATION --

Sludge is applied to a 1-hectare pasture planted in a forage crop that is being actively grazed by 12 cows. The amount is determined by the variable APRATE and the pathogen population by the variable ASCRS. The sludge-covered pasture is then chain-harrowed, an operation which spreads the sludge evenly over the whole pasture and knocks some of it from the forage-crop surface to the soil surface. At the end of APPLICATION the applied sludge is distributed between Compartment 5, SOIL SURFACE, and Compartment 6, CROP SURFACE. The user may determine the division of sludge between these two compartments by specifying a value for the variable ASLSUR. This variable specifies the percentage of the total pathogen population in applied sludge that reaches the SOIL SURFACE. The remaining sludge is assumed to cling to the forage CROP SURFACE. The default value for ASLSUR is an unsupported estimate.

There are four transfers out of this compartment. During the spreading of sludge and the subsequent harrowing operation, dust is generated. This is simulated by a transfer of sludge-associated pathogens by TAU13 to Compartment 3, PARTICULATES. The amount of sludge transferred when the default value of WTPAR3 is used was calculated by assuming the production of 15 milligrams of particulates per cubic meter in the 10-meter high volume above the entire 1-hectare pasture. This weight of sludge is divided by the weight of sludge applied (APRATE) and is then multiplied by the number of pathogens in Compartment 1 to determine the number of pathogens transferred to PARTICULATES. This transfer occurs 1 hour into the pathway.

Sludge adheres to spreading and harrowing equipment. A weight of sludge specified by the variable WTRES2 is transferred to Compartment 2, RESIDUE, by TAU12. The number of pathogens associated with the transferred sludge is calculated in the same manner as the particulate-associated pathogens above. This transfer occurs 2 hours into the pathway.

At the end of activities for this compartment the transfers are made to Compartment 5, SOIL SURFACE, and the Compartment 6, CROP SURFACE, by TAU15 and TAU16, respectively.

Time of first transfer into compartment - Start of pathway.

Time of last transfer out of compartment - 3 hours into pathway.

Process function - RH01
Activated: Start of pathway.
Duration: 3 hours.
Rates: Salmonella: 0.0*N(1)/hour.
Ascaris: 0.0*N(1)/hour.
Poliovirus: 0.0*N(1)/hour.

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Transfers into compartment -
TAU01 = ASCIN, Transfer occurs at start of pathway.

Transfers out of compartment -
TAU12 = (WTRES2/(APRATE - WTPAR3)*N(1), Transfer occurs 2 hours into pathway
TAU13 = (WTPAR3/APRATE)*N(1), Transfer occurs 1 hour into pathway.
TAU15 = ASLSUR*N(1), Transfer occurs 3 hours into pathway.
TAU16 = (1. - ASLSUR)*N(1), Transfer occurs 3 hours into pathway.

Compartment 2, RESIDUE --

RESIDUE is left on equipment at the end of the APPLICATION compartment. The amount is determined by the variable WTRES2. The default value for this variable is an estimate. The material in RESIDUE compartments is assumed to dry out rapidly. The process functions assigned to this and other RESIDUE compartments reflect the effects of desiccation on the model pathogens.

Time of first transfer into compartment - 2 hours into pathway.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RHO2
Activated: 3 hours into the pathway.
Duration: Until all pathogens are depleted or the pathway ends.
Rates: Salmonella: -0.46*N(2)/hours. (8)
Ascaris: -0.25*N(2)/hours. (22, 40, 74)
Poliovirus: -0.38*N(2)/hours. (88, 97)

Transfers into compartment -
TAU12 = (WTRES2/(APRATE - WTPAR3))*N(1), Transfer occurs 2 hours into pathway.

Transfers out of compartment - None.

Compartment 3, PARTICULATES --

The activities described for Compartment 1 will generate airborne dust or PARTICULATES. It is assumed in all PARTICULATES compartments that the dust is generated at the start of activities in the compartment from which the transfer to PARTICULATES is made, in this case Compartment 1 - APPLICATION, and that the dust and its associated pathogens remain at the initial concentration until the generating activity ceases. The process functions in all PARTICULATES compartments are delayed to allow for maximum inhalation of pathogens during generation activities.

The user may specify the amount of sludge being transferred to this compartment by assigning a value to WTPAR3. There are two compartments

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described by the title "PARTICULATES" in this pathway: Compartment 3 and Compartment 4. To avoid confusion in this and other pathways a naming system was used in which the "weight transferred to PARTICULATES" is abbreviated "WTPAR" and the number of the compartment concerned is appended. For example, WTPAR3 is the weight of sludge transferred to PARTICULATES in Compartment 3.

The default value assigned WTPAR3 was determined by assuming that PARTICULATES are generated to a level of 15 mg/m³ in a volume extending 10 meters above the 1-hectare pasture. The concentration of particules and the height of the volume considered are the same in all PARTICULATES compartments but the area under the dust cloud differs between pathways.

The process functions for PARTICULATES are the same as for RESIDUE and reflect the effects of rapid desiccation of the airborne material and the pathogens associated with it.

Time of first transfer into compartment - 1 hour into pathway.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RHO3
Activated: 3 hours into pathway.
Duration: Until all pathogens are depleted or the pathway ends.
Rates: Salmonella: -0.46*N(3)/hour. (8)
Ascaris: -0.25*N(3)/hour. (22, 40, 74)
Poliovirus: -0.38*N(3)/hour. (88, 97)

Transfers into compartment -
TAU13 = WTPAR3/APRATE*N(1), Transfer occurs 1 hour into pathway.

Transfers out of compartment - None.

Compartment 4, PARTICULATES --
The PARTICULATES generated in this compartment represent the dust raised by normal winds and the milling of cattle in the pasture. The dust blown up from the SOIL SURFACE is simulated by transfer TAU54. The amount of sludge-amended soil involved is specified by assigning a value to WTPAR4. The default value for this variable assumes that 15 milligrams of dust is generated for each cubic meter of air in the 10-meter high volume above the 1-hectare pasture. PARTICULATES are generated every day for the duration of the pathway. Process functions are delayed to allow for maximum exposure by workers who might enter the pasture.

Time of first transfer into compartment - 4 hours into pathway.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

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Process function - RH04
Activated: 16 hours into the pathway.
Duration: Until all pathogens are depleted or the pathway ends.
Rates: Salmonella: -0.46*N(4)/hour. (8)
Ascaris: -0.25*N(4)/hour. (22, 40, 74)
Poliovirus: -0.38*N(4)/hour. (88, 97)

Transfers into compartment -
TAU54 = (WTPAR4/((APRATE - WTRES2 - WTPAR3)*ASLSUR))*N(5),
Transfer occurs at 4 hours into the pathway and then every 24 hours.

Transfers out of compartment - None

Compartment 5, SOIL SURFACE --

In a pasture with a standing forage, a fraction of the sludge applied would land on the SOIL SURFACE. Even though the pasture is not plowed, the SOIL SURFACE includes the upper 10 centimeters of the soil profile. This layer is subjected to weekly changes in moisture as a result of irrigation. It is at field capacity (20 percent weight/weight) after each irrigation and dries linearly to the wilting point (4 percent weight/weight) between irrigations. Pathogen process functions are tied to the irrigation cycle. The rate of growth or inactivation of pathogens is dependent on the ambient temperature of the environment and on the available water. The ambient temperature is set by the variable TEMP and is constant throughout the pathway. The available water is a function of the time elapsed since the last irrigation.

Sludge fertilizer and pathogens are first transferred into this compartment from the APPLICATION compartment by TAU15. As the pathway progresses several other transfers occur. At irrigation, water from Compartment 14, IRRIGATION WATER, is transferred to Compartment 8, SOIL SURFACE WATER. This water then percolates into the soil, transferring pathogens to SOIL SURFACE by TAU85. The pathogens involved in this transfer may be either soil pathogens which become suspended in the water during irrigation, a phenomenon simulated by TAU58, or pathogens introduced with the irrigation water itself. In a similar manner, after pathogens have been transferred to CROP SURFACE, some will be returned to SOIL SURFACE when gravity and wind cause dust on the crop to fall to the ground (TAU65). Pathogens also enter this compartment when the grazing cattle deposit manure on the ground; an event which occurs once each day and is shown by TAU125.

There is one other way for pathogens to enter this compartment. The user may place an initial pathogen population in any pathway compartment by specifying the compartment number and the desired population in the POPL variable of the $ARGS name list. The mechanism for handling variable specification is fully described in the user's manual for the program (in Appendix A). Specifying an initial pathogen population allows the user to examine the effects of several sludge applications. The final compartment populations of one model run would be input as initial populations in the

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next run. Environmental conditions may be unique for each run, or standard default values may be use.

Pathogens are transferred from this compartment into Compartment 4, PARTICULATES, by TAU54; Compartment 7, SUBSURFACE SOIL, by TAU57; Compartment 8, SOIL SURFACE WATER, by TAU58; Compartment 6, CROP SURFACE, by TAU56; Compartment 10, ANIMAL CONSUMPTION, by TAU510; and to SURFACE RUNOFF by TAU50. PARTICULATES are generated daily by wind and milling cattle. The transfer from SOIL SURFACE to SUBSURFACE SOIL occurs after each irrigation when irrigation water percolates below the 10-centimeter mark which separates SOIL SURFACE from SUBSURFACE SOIL. The time of this transfer is controlled by the SOIL SURFACE WATER infiltration rate, a parameter the user may specify in the variable FILTR8. The infiltrating water carries pathogens with it. The fraction of the total population in SOIL SURFACE transferred by percolating water to SUBSURFACE SOIL is specified in the variable SSTSSS. The default values for this variable are estimates that take into account the size and soil-binding capabilities of each pathogen.

Pathogens associated with SOIL SURFACE are suspended in irrigation water while it is lying on the surface of the pasture and is considered to be in Compartment 8, SOIL SURFACE WATER. This transfer occurs at the beginning of each irrigation cycle. The fraction of total SOIL SURFACE pathogens suspended in SOIL SURFACE WATER is determined by the variable SSTSSW. These pathogens and any introduced with IRRIGATION WATER are transferred to SOIL SURFACE when the irrigation water percolates into the soil.

A portion of the dust raised by grazing cattle is assumed to contact and then cling to the surface of the forage crop. This transfer of soil and soil-associated pathogens to CROP SURFACE occurs once each day. The weight of soil involved in the transfer is specified in the variable SURCRP. As explained in item e of the General Considerations for this pathway, cows consume soil as well as forage when grazing. The amount of soil transferred each day to ANIMAL CONSUMPTION is specified by the variable SCNSMP.

The transfer to SURFACE RUNOFF simulates the effects of a rain and occurs at TRAIN. SURFACE RUNOFF is not a compartment because the scope of this model is not large enough to follow pathogens beyond the 1 hectare which constitutes the pasture. SURFACE RUNOFF by definition leaves the pasture area. The rain which produces runoff is an arbitrary event which does not occur under default conditions. The user must set TRAIN to a positive number for rain to occur. The number will equal the time in hours when the rain occurs. The user may also control the number of pathogens washed from the SOIL SURFACE and removed from the pathway by TAU50 by specifying the value of FRAIN.

Time of first transfer out of compartment - 3 hours into pathway.

Time of last transfer out of compartment - End of pathway.

Process function - RHO5
Activated: 4 hours into pathway.

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Duration: Until the end of the pathway.

Rates: Salmonella: 0.070*N(5)/hour, for 20 ≤ TEMP < 45 and of TIRRG ≤ 3.5 days. The growth of salmonella is assumed to occur at one-half the rate for E.coli in the sterile compost. (62)

-0.012*N(5)/hour, for 20 ≤ TEMP < 45 and 3.5 < TIRRG ≤ 5.5 days. (23, 72, 73)

-0.46*N(5)/hour, for TEMP < 45 and 5.5 < TIRRG < 7 days. (8)

-3.45*N(5)/hour, for TEMP ≥ 45 and any time. (8, 93)

0.0*N(5)/hour, for TEMP < 20 and any time. No changes in pathogen population are assumed for temperatures less than 20°C.

Ascaris: -0.0005*N(5)/hour, for TEMP < 40 and 8 hours < TIRRG ≤ 5.5 days. (83)

-1.54*N(5)/hour, for 40 ≤ TEMP < 50 and 8 hours < TIRRG ≤ 5.5 days. (7, 78)

-0.25*N(5)/hour, for TIRRG > 5.5 days and any temperature. (22, 40, 74)

Poliovirus: -0.005*N(5)/hour, for 15 < TEMP < 45 and 8 hours < TIRRG ≤ 6.5 days. (27, 96)

-0.027*N(5)/hour, for TEMP < 45 and TIRRG > 6.5 days. (87, 96)

-0.38*N(5)/hour, for TEMP ≥ 45 and any time. (88, 77)

-0.00087*N(5)/hour, for TEMP < 15 and 8 hours < TIRRG < 6.5 days. (96)

Transfers into compartment -

TAU15 = ASLSUR*N(1), Transfer occurs 3 hours into pathway.
TAU65 = (TCSTSS/24.)*N(6), Transfer occurs hourly after 3 hours into pathway.
TAU85 = N(8) - TAU86, Transfer occurs after each irrigation at TIRRG + (DEPTH/FILTR8).
TAU125 = TMSSUR*(N(12) - TA1216 - TA1215), Transfer occurs every 24 hours from 31 hours into pathway.

Transfers out of compartment -

TAU50 = FRAIN*N(5), Transfer occurs if a rain is specified and then at TRAIN.
TAU54 = (WTPAR4/((APRATE - WTRES2 - WTPAR3)*ASLSUR))*N(5), Transfer occurs at 4 hours into the pathway and then every 24 hours.
TAU56 = (SURCRP/(ASLSUR*(APRATE - WTRES2 - WTPAR3)))*N(5), Transfer occurs at 24 hour intervals from 4 hours.
TAU57 = SSTSSS*N(5), Transfer occurs after each irrigation at (DEPTH/FILTR8) + 1 hour.

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TAU58 = SSTSSW*N(5), Transfer occurs at each irrigation.
TAU510 = (SCNSMP/(ASLSUR*(APRATE - WTRES2 - WTPAR)))*N(5), Transfer occurs at 24-hour intervals from 5 hours.

Compartment 6, CROP SURFACE --
In a pasture with a standing crop, a fraction of the sludge applied would land on the CROP SURFACE, a transfer shown in TAU16. The user can control the distribution of sludge between Compartment 5, SOIL SURFACE, and Compartment 6 by specifying the value of ASLSUR. As the pathway progresses there are several other transfers into this compartment. The cattle grazing the pasture stir up dust from the SOIL SURFACE. Some of the dust (an amount specified by SURCRP) will cling to the CROP SURFACE. This transfer, TAU56, occurs daily. The grazing cows also contribute MANURE to the pasture, some of which lands on the CROP SURFACE and may carry a pathogen load. TAU126, the transfer of manure-associated pathogens, occurs daily. The crop is washed by irrigation water once each week. As the water soaks into the soil a fraction of the pathogens in Compartment 8, SOIL SURFACE WATER, are transferred by TAU86 to CROP SURFACE. This fraction is controlled by the variable SSWTCS.

Pathogens can be transferred from this compartment back to Compartment 5, SOIL SURFACE, as dust and leaves fall to the ground. TAU65 is a continuing transfer throughout the pathway, with a fraction of the total population of Compartment 6 (TCSTSS) transferred each hour. During irrigation, a fraction of the total population (variable CSTSSW is calculated to be that part associated with water-covered foliage when the irrigation depth is 6 inches or 15.24 centimeters) is suspended in SOIL SURFACE WATER. Pathogens are also transferred from this compartment when cows consume the crop.

The user may specify the dry weight of forage consumed by the 12 grazing cows each day by assigning a value to the variable FORAG. The default value is an average consumption for a lactating dairy cow. The user may also specify how much of the forage is sludge by defining FSLDGE. These factors are divided by the weight of sludge in the compartment to determine the total weight of sludge consumed and thus the pathogen population consumed. While cows eat continuously, the transfer from CROP SURFACE to ANIMAL CONSUMPTION, TAU610, is made once a day.

Time of first transfer into compartment - 3 hours into pathway.

Time of last transfer out of compartment - End of pathway.

Process function - RH06
Activated: 4 hours into pathway.
Duration: Until the end of the pathway.
Rates: Salmonella: -0.096*N(6)/hour. (72, 73)
Ascaris: -1.54*N(6)/hour. (7, 78)
Poliovirus: -0.069*N(6)/hour. (49)

Transfers into compartment -

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TAU16 = (1. - ASLSUR)*N(1), Transfer occurs 3 hours into pathway.
TAU56 = (SURCRP/(ASLSUR*(APRATE - WTRES2 - WTPAR3)))*N(5), Transfer occurs at 24-hour intervals from 4 hours into pathway.
TAU86 = SSWTCS*N(8), Transfer occurs after each irrigation at TIRRG + (DEPTH/FILTR8).
TAU126 = (1. - TMSSUR)*(N(12) - TA1216 - TA1215), Transfer occurs at 24-hour intervals from 31 hours into pathway.

Transfers out of compartment -
TAU65 = (TCSTSS/24.)*N(6), Transfer occurs hourly from 4 hours into pathway.
TAU68 = CSTSSW*N(6), Transfer occurs at each irrigation.
TAU610 = (FORAG*FSLDGE)/((1. - ASLSUR)*(APRATE - WTRES2 - WTPAR3))*N(6), Transfer occurs at 24-hour intervals from 5 hours into pathway.

Compartment 7, SUBSURFACE SOIL --

This compartment represents the soil from 10 to 80 centimeters below the surface. This SUBSURFACE SOIL is at constant moisture (field capacity, 20 percent weight/weight) and temperature (15°C). Pathogens from the sludge and manure fertilized upper 10 centimeters of soil are transferred into this compartment with percolating irrigation water. The fraction of the total SOIL SURFACE (Compartment 5) pathogen population transferred is determined by the variable SSTSSS. The time of the transfer by TAU57 is controlled by the depth of irrigation water which must soak in (DEPTH) and the rate of water infiltration (FILTR8), but the transfer occurs after each irrigation.

Pathogens may be transferred to Compartment 13, GROUNDWATER, by TAU713. The variable SSTGW, which specifies the fraction of total SUBSURFACE SOIL pathogens transferred, is set to zero under default conditions. The 6 centimeters of applied irrigation water specified by default values would only penetrate to 60 centimeters, precluding transfer to GROUNDWATER. The user should specify a value for SSTGW if DEPTH is set to more than 6 centimeters. Pathogens which are not transferred to GROUNDWATER are transferred from this compartment to the SOIL SINK at the end of the pathway.

The SOIL SINK is not defined as a compartment in this model. It represents both pathogens bound to soil and deeper soil not likely to come into contact with the surface.

Time of first transfer into compartment - TIRRG + (DEPTH/FILTR8).

Time of last transfer out of compartment - End of pathway.

Process function - RH07
Activated: TIRRG + (DEPTH/FILTR8).
Duration: Until the pathway ends.
Rates: Salmonella: -0.012*N(7)/hour. (23, 72, 73)

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Ascaris: -0.00053*N(7)/hour. (83)
Poliovirus: -0.0049*N(7)/hour. (27, 96)

Transfers into compartment -
TAU57 = SSTSSS*N(5), Transfer occurs after each irrigation at TIRRG + (DEPTH/FILTR8).

Transfers out of compartment -
TAU70 = N(7), Transfer occurs at the end of the pathway (720 hours).
TAU713 = SSTGW*N(7), Transfer occurs after each irrigation at TIRRG + (DEPTH/FILTR8) + 2 hours and also after rain at TRAIN + (DEPTH/FILTR8) + 2 hours.

Compartment 8, SOIL SURFACE WATER --

Irrigation in this model involves flooding the pasture with water to a uniform depth (specified by the variable DEPTH) and then allowing the water to infiltrate the soil at a constant rate (specified by the variable FILTR8). The water transfers into SOIL SURFACE WATER from Compartment 14, IRRIGATION WATER, by TAU148 and may carry with it a pathogen load. Pathogens in SOIL SURFACE and on the CROP SURFACE will become suspended in the overlying water. These transfers from Compartment 5 and Compartment 6, respectively, will occur for each weekly irrigation (TIRRG) starting 4 hours into the pathway.

The variable TIRRG is used in several ways in the model. Its value is incremented by 168 hours each time it is used so that irrigation occurs at weekly intervals after the first irrigation, 4 hours into the pathway. The variable is also used in the process functions for Compartment 5 to keep track of the time elapsed since the last irrigation.

Pathogens transfer back to Compartment 5, SOIL SURFACE, and Compartment 6, CROP SURFACE, when the irrigation water soaks into the soil. While this would normally be a gradual process, TAU85 and TAU86 occur at the end of irrigation as a single transfer to each compartment.

Time of first transfer into compartment - 4 hours into pathway (at the first irrigation).

Time of last transfer out of compartment - After the last irrigation at 676 + (DEPTH/FILTR8) hours.

Process function - RH08
Activated: TIRRG (with each irrigation).
Duration: DEPTH/FILTR8.
Rates: Salmonella: 0.23*N(8)/hour. A 3-hour generation time is assumed for growth of salmonella suspended in irrigation water.
Ascaris: 0.0*N(8)/hour.
Poliovirus: 0.0*N(8)/hour. No change is assumed for ascaris and poliovirus suspended in irrigation water.

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Transfers into compartment -

TAU58 = SSTSSW*N(5), Transfer occurs at each weekly irrigation, starting 4 hours into the pathway.
TAU68 = CSTSSW*N(6), Transfer occurs at each weekly irrigation, starting 4 hours into pathway.
TAU148 = N(14), Transfer occurs at each weekly irrigation, starting 4 hours into pathway.

Transfers out of compartment -

TAU85 = N(8) - TAU86, Transfer occurs after each irrigation at TIRRG + (DEPTH/FILTR8).
TAU86 = SSWTCS*N(8), Transfer occurs after each irrigation at TIRRG + (DEPTH/FILTR8).

Compartment 9, MEAT --

If the beef cow option is chosen (the variable COW is set by the user to -1.), the cows grazing the pasture will be slaughtered at TSLOTR. This variable must be set by the user to be a time less than 30 days (the time the pathway ends under default values). Slaughter will occur when pathogen levels in the cows are highest on the day assigned to TSLOTR. At slaughter, the cows become 3240 kilograms of MEAT (12 cows x 270 kilograms per cow). Pathogens can be transferred to MEAT by two routes. Salmonella can infect a cow. TAU109 simulates the direct transfer of pathogens from ANIMAL CONSUMPTION, Compartment 10, to MEAT. The default value for DTCTMT is zero since no data could be found quantifying the contamination of meat from a systemic salmonella infection and neither ascaris nor poliovirus should transfer from the gut of the cow. The user can assign a value to DTCTMT if contamination of MEAT by a systemic infection is desired. The transfer would occur daily but only for salmonella pathogen type.

When cattle are butchered, the MEAT is often contaminated by enteric bacteria. The model shows this transfer as being between the manure-contaminated HIDE and the MEAT. TAU159 will occur at TSLOTR. Default values for FRSLOT, the fraction of HIDE pathogens transferred to MEAT, are available for all three pathogen types. These are, of course, estimates. MEAT is assumed to be kept at 4°C following slaughter. There are no transfers out of this compartment but the pathogen population is used in meat-exposure risk calculations.

Time of first transfer into compartment - 28 hours into the pathway.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathway terminates.

Process function - RH09

Activated: 32 hours into pathway.
Duration: Until the pathway ends.
Rates: Salmonella: 0.076*N(9)/hour to an upper limit of 1×10^9 salmonella per kilogram of meat. Salmonella is allowed to grow at a generation time of 6 hours at 4°C.

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Ascaris: $0.0*N(9)$/hour.
Poliovirus: $0.0*N(9)$/hour. Poliovirus and ascaris remain at the level transferred at slaughter.

Transfers into compartment -
TAU109 = DTCTMT*N(10), Transfer occurs 28 hours into the pathway and then at 24-hour intervals.
TAU159 = FRSLOT*N(15), Transfer occurs at TSLOTR.

Transfers out of compartment - None.

Compartment 10, ANIMAL CONSUMPTION --
Twelve cows are grazing the pasture at the time of sludge application. This compartment represents those cows as they consume the growing pasture crop and digest it. Pathogens can be transferred into this compartment from two sources, CROP SURFACE by TAU610 and SOIL SURFACE by TAU510. No provision is made for possible ingestion of irrigation water during the time when the pasture is flooded. Although grazing is a continuous process, the transfers into this compartment are made once a day as discrete events starting 5 hours into the pathway.

In the absence of data, it was assumed that herbivore digestive processes would not alter ingested pathogen populations. The possibility of infection by salmonella was taken into account. If the total daily transfer of pathogens into the compartment exceeds 1×10^9 salmonella per cow, infection is simulated by increasing the population in the compartment by three orders of magnitude and excreting this larger number in the manure. Transfers TAU109 and TA1011, from ANIMAL CONSUMPTION to MEAT and MILK, may also be used to simulate the effects of salmonella infection. While the default values for both DTCTMT and DTCTMK (the variables which specify the fraction of direct transfer of salmonella from ANIMAL CONSUMPTION to MEAT and MILK, respectively) are zero, the user may input values to indicate contamination of foodstuffs as a result of systemic infection.

Materials which are consumed by the cows have a 2-day residence time before being excreted to MANURE by TA1012. One-half of the pathogen population of Compartment 10 is transferred to Compartment 12 each day as a discrete event.

Time of first transfer into compartment - 5 hours into pathway.

Time of last transfer out of compartment - End of pathway.

Process function - RH010
Activates: 5 hours into pathway.
Duration: Until the pathway ends.
Rates: Salmonella: If $(TAU610 + TAU510) \geq 1 \times 10^9$/cow, there is an immediate increase to $1 \times 10^3*N(10)$. If $(TAU610 + TAU510) \leq 1 \times 10^9$/cow, there is no change in the

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population in this compartment, 0.0*N(10)/hour.
Ascaris: 0.0*N(10)/hour.
Poliovirus: 0.0*N(10)/hour.

Transfers into compartment -
TAU510 = (SCNSMP/(ASLUR*(APRATE - WTRES2 - WTPAR3)))*N(5), Transfer occurs at 24-hour intervals from 5 hours.
TAU610 = ((FORAG*FSLDGE)/((1. - ASLSUR)*(APRATE - WTRES2 - WTPAR3)))*N(6), Transfer occurs at 24-hour intervals from 5 hours.

Transfers out of compartment -
TAU109 = DTCTMT*N(10), Transfer occurs at 28 hours into the pathway and then at 24-hour intervals.
TA1011 = DTCTMK*N(10), Transfer occurs at 12-hour intervals from 28 hours.
TA1012 = N(10)/2., Transfer occurs at 24-hour intervals from 30 hours into the pathway.

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Compartment 11, MILK --

The cows are milked twice each day when the dairy cow option is chosen (COW = +1.). This is the default condition. The MILK is kept at 4°C for 11 hours but is assumed to be removed from the pathway before the next milking. Pathogens can be transferred to MILK directly from Compartment 10, ANIMAL CONSUMPTION, by TA1011. This transfer will simulate the possible effects of a systemic salmonella infection. The user must supply a value for DTCTMK, the variable which specifies the fraction of Compartment 10 pathogens transferred. The default value for this variable is zero. Neither poliovirus nor ascaris are known to infect cattle and would not pass from the gut.

Pathogens are more readily transferred into milk by dirty utensils and careless handling. In the model these are combined as a transfer from manure-contaminated UDDER, Compartment 16. Transfer TA1611 occurs at each milking. All three pathogens can enter MILK by this route. The default value for UDRMLK is an estimate. There are no transfers out of this compartment but the pathogen population is used in milk-exposure risk calculations.

Time of first transfer into compartment - 28 hours into pathway.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathway terminates.

Process function - RH011
Activated: 32 hours into the pathway.
Duration: 11 hours after each milking.

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Rates:

Salmonella: $0.076*N(11)$/hour to a limit of 1×10^{12} salmonella per milliliter of milk. Salmonella is allowed to grow at a generation time of 6 hours at 4°C.

Ascaris: $0.0*N(11)$/hour.

Poliovirus: $0.0*N(11)$/hour. Poliovirus and ascaris remain at the level transferred in.

Transfers into compartment -

TA1011 = DTCTMK*N(10), Transfer occurs at 12-hour intervals from 28 hours.

TA1611 = UDRMLK*N(16), Transfer occurs at 12-hour intervals from 32 hours into pathway.

Transfers out of compartment - None.

Compartment 12, MANURE --

Each day one-half of the pathogen population in Compartment 10, ANIMAL CONSUMPTION, is transferred to MANURE by TA1012. The inactivation of pathogens in MANURE is a function of both the ambient temperature of the pathway (set in the variable TEMP) and the moisture content of the manure. Each day's manure dries separately as shown below in significant calculations.

Depending upon which type of cow is grazing the pasture, a fraction of the deposited MANURE will contact HIDE or UDDER. When the beef cow option is selected (COW = -1.), TA1215 transfers a fraction of the total pathogen population in MANURE (as specified by TMHIDE) to Compartment 15, HIDE, at the time of deposition. When the dairy cow option is operating (COW = +1.), TA1216 transfers a fraction of the pathogens to Compartment 16, UDDER. These transfers allow indirectly for the contamination of MEAT and MILK.

Regardless of the type of cattle involved, some MANURE lands on the CROP SURFACE and some on the SURFACE SOIL. These transfers are calculated by TAU126 and TAU125, respectively. The variable TMSSUR controls the distribution of manure between CROP SURFACE and SURFACE SOIL.

Significant calculations - Drying of manure is based upon an 8-centimeter thick layer of 20 percent solids manure evaporating at 0.7 times the clear water evaporation rate for the Albuquerque, New Mexico area.

Percent solids (PRSOL) = $100 - (-5.33T + 80.0)$, where T = days after first deposit of manure.

Time of first transfer into compartment - 30 hours into pathway.

Time of last transfer out of compartment - End of pathway.

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Process function - RH012

Activated: 31 hours into pathway.

Duration: Until the pathway ends.

Rates:

Salmonella:
- -0.46*N(12)/hour, for PRSOL ≥ 80. (8)
- -3.45*N(12)/hour, for PRSOL $\overline{<}$ 80 and TEMP > 45. (8, 93)
- -0.048*N(12)/hour, for PRSOL < 80 and TEMP < 45. (8)

Ascaris:
- -0.251*N(12)/hour, for PRSOL ≥ 95. (22, 40, 74)
- -1.535*N(12)/hour, for PRSOL < 95 and TEMP > 40. (7, 78) 0.0*N(12)/hour, for PRSOL < 95 and TEMP < 40.

Poliovirus:
- -0.384*N(12)/hour, for TEMP ≥ 45. (88, 97)
- -0.0192*N(12)/hour, for TEMP < 45 and PRSOL < 65. (87)
- -0.0104*N(12)/hour, for TEMP < 45 and PRSOL ≥ 65. (44, 87)

Transfers into compartment -

TA1012 = N(10)/2., Transfer occurs at 24-hour intervals from 30 hours into the pathway.

Transfers out of compartment -

TAU125 = TMSSUR*(N(12) - TA1216 - TA1215), Transfer occurs at 24-hour intervals from 31 hours into pathway.

TAU126 = (1. - TMSSUR)*(N(12) - TA1215), Transfer occurs at 24-hour intervals from 31 hours.

TA1215 = TMHIDE*N(12), Transfer occurs at 24-hour intervals from 31 hours for COW = -1.

TA1216 = (0.5*TMHIDE)*N(12), Transfer occurs at 24-hour intervals from 31 hours for COW = +1.

Compartment 13, GROUNDWATER --

Pathogens applied to a pasture may contaminate groundwaters if surface water percolates deeply enough. The default values incorporated into the model preclude such contamination but, as explained in Compartment 7, the user may specify a transfer of pathogens to GROUNDWATER in order to model the effects of heavy irrigation.

Pathogens transferred to GROUNDWATER would slowly be inactivated as shown in the process functions listed below. Pathogens would also be dispersed throughout the aquifier. The user may determine the effects of dispersion by specifying a value for GNDIL. This variable is included in the equation for TA1314 and affects the pathogen number transferred to Compartment 14, IRRIGATION WATER. Another variable in the equation for TA1314 is FRGIR. It determines what fraction of the water used for irrigation is from GROUNDWATER by specifying the fraction of the pathogens present that will be transferred on. The default values for these variables were not chosen to model any particular situation. One-half of the

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water in Compartment 14 is from GROUNDWATER while the aquifier dilutes incoming percolation by 1 x 10^6 when default values are used.

Time of first transfer into compartment - After the first irrigation at 4 hours + (DEPTH/FILTR8) + 2 hours.

Time of last transfer out of compartment - 1 hour before last irrigation (675 hours).

Process function - RH013
Activated: At time of first transfer in.
Duration: Until end of pathway.
Rates:

Rates:	Salmonella:	-0.012*N(13)/hour.	(23, 72, 73)
	Ascaris:	-0.00053*N(13)/hour.	(83)
	Poliovirus:	-0.0119*N(13)/hour.	(95)

Transfers into compartment -
TAU713 = SSTGW*N(7), Transfer occurs after each irrigation at TIRRG + (DEPTH/FILTR8) + 2 hours and also after rain at TRAIN + (DEPTH/FILTR8) + 2 hours.

Transfers out of compartment -
TA1314 = GNDIL*FRGIR*N(13), Transfer occurs 1 hour before each irrigation.

Compartment 14, IRRIGATION WATER --

In this compartment water from two sources is combined. Water is transferred into the compartment from GROUNDWATER by TA1314 and from an EXTERNAL SOURCE by TAU014. GROUNDWATER represents well water used here for irrigation. It may contain pathogens which have been carried through SUBSURFACE SOIL by deep percolation (TAU713). EXTERNAL SOURCE represents surface flows used for irrigation. This water may also contain pathogens. The user may specify the level of contamination by assigning a value to the variable EXTRN. The ratio of GROUNDWATER to EXTERNAL SOURCE water is determined by the variable FRGIR.

EXTERNAL SOURCE is not defined as a pathway compartment since it is beyond the scope of this model to consider water pollution other than the possible additive effects of using contaminated water on a sludge-fertilized field. The IRRIGATION WATER compartment has a very short duration and no process functions have been defined. The compartment does not represent a physical part of the environment but rather the transition between several states. As soon as the waters are mixed they become SOIL SURFACE WATER, represented by Compartment 8. This transfer is accomplished by TAU148 at weekly intervals.

Time of first transfer into compartment - 3 hours into pathway.

Time of last transfer out of compartment - Transfers are made from this compartment for each irrigation. The last transfer will occur for the last irrigation at 700 hours.

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Process function - RH014
Activated: 3 hours into pathway.
Duration: 1 hour.
Rates: Salmonella: 0.0*N(14)/hour.
Ascaris: 0.0*N(14)/hour.
Poliovirus: 0.0*N(14)/hour.

Transfers into compartment -
TAU014 = EXTERN, Transfer occurs 1 hour before the first irrigation and then at weekly intervals.
TA1314 = FRGIR*GNDIL*N(11), Transfer occurs 1 hour before the first irrigation and then at weekly intervals.

Transfers out of compartment -
TAU148 = N(14), Transfer occurs at each TIRRG.

Compartment 15, HIDE --

This compartment represents the HIDE of the grazing cattle. Each day pathogens are transferred from Compartment 12, MANURE, to HIDE by TA1215. The user may specify the fraction of transfer by supplying a value for TMHIDE. If the beef cow option is selected (COW = -1.), a fraction of the pathogens on the HIDE will be transferred to MEAT at the time of slaughter on the day specified in TSLOTR. This fraction is specified by variable FRSLOT.

Time of first transfer into compartment - 31 hours into pathway.

Time of last transfer out of compartment - TSLOTR.

Process function - RH015
Activated: 33 hours in pathway.
Duration: 1 hour.
Rates: Salmonella: -N(15)/hour.
Ascaris: -N(15)/hour.
Poliovirus: -N(15)/hour.

Transfers into compartment -
TA1215 = TMHIDE*N(12), Transfer occurs at 24-hour intervals from 31 hours.

Transfers out of compartment -
TAU159 = FRSLOT*N(15), Transfer occurs on day TSLOTR, 1 hour after TA1215.

Compartment 16, UDDER --

This compartment provides for an indirect transfer of MANURE-associated pathogens to MILK. Pathogens are transferred from Compartment 12, MANURE, to UDDER by TA1216 once each day. The number transferred is controlled by the variable TMHIDE which specifies the transfer to Compartment, 15, HIDE. If the dairy cow option is selected (COW = +1.), a fraction of

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the pathogens on UDDER will be transferred to MILK during each milking. This fraction is specified by the variable UDRMLK.

Time of first transfer into compartment - 31 hours into pathway.

Time of last transfer out of compartment - 4 hours before the pathway ends.

Process function - RH016
    Activated: 31 hours into pathway.
    Duration: Until pathway ends.
    Rates: Salmonella: -(TA1212/24.)/hour.
        Ascaris: -(TA1216/24.)/hour.
        Poliovirus: -(TA1216/24.)/hour.

Transfers into compartment -
    TA1216 = 0.5*TMHIDE*N(12), Transfer occurs at 24-hour intervals from 31 hours into pathway.

Transfers out of compartment -
    TA1611 = UDRMLK*N(16), Transfer occurs at 12-hour intervals from 32 hours.

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Job A

PATHWAY 6 - SLUDGE APPLICATION PATHWAY - FERTILIZER FOR CROPS THAT ARE PROCESSED PRIOR TO ANIMAL CONSUMPTION

General Considerations

This pathway describes the fate of sewage sludge pathogens after the application of dried raw or anaerobically digested sludge to a 1-hectare field planted in a forage crop such as alfalfa. The crop is growing at the time of sludge application and is cut and baled before being used as an animal feed. The pathway can accommodate other processing steps such as ensiling, but these are not included in the model at this time. Figure 6 shows the process compartments and transfers which define this application regime. The differential equations which describe this pathway are presented in Table 6a. Each process function and transfer function is defined in the following section. Table 6b lists the definitions of and default values for the input variables used to define environmental factors which affect process and transfer functions. The model user may supply a value for any input variable and, thus, set the program to model a specific situation of concern. Table 6b also lists output variables generated by the computer program. These variables are not available to the user as input but are often used in pathway descriptions to define time increments and pathogen levels. The general considerations and assumptions discussed below were made to facilitate model development.

a. The pathway divides into two parts. The first includes application of sludge to the field, irrigation of the field, growth of the crop, and the cutting and baling of the crop. The second part of the pathway includes storage of the baled crop and the consumption of that crop by cows. The duration of the pathway is determined by the user. It is equal to the time when the crop is cut, specified in the variable TCUT; plus a 7-day drying time; plus the time the crop is in storage, specified by the variable STORAG; plus the time the crop is eaten by cows, specified by the variable COWS. Under default conditions these activities will continue for 97 days. If the beef cow option is chosen (COW = -1.), the pathway will terminate on the day of slaughter specified in the variable TSLOTR, regardless of the values given other time parameters.

   Several cycles of growth and harvest may be simulated by using the final pathogen counts in each compartment as the initial conditions of each compartment in a subsequent run. This is done by specifying each compartment number and the desired pathogen population for each compartment in the POPL variable of the $ARGS name list. The mechanism for setting initial pathogen populations is described in the user's manual for the program (Appendix A).

b. The ambient temperature of the environment is specified for each run of the model by the variable TEMP and remains constant throughout. The default ambient temperature is 20°C.

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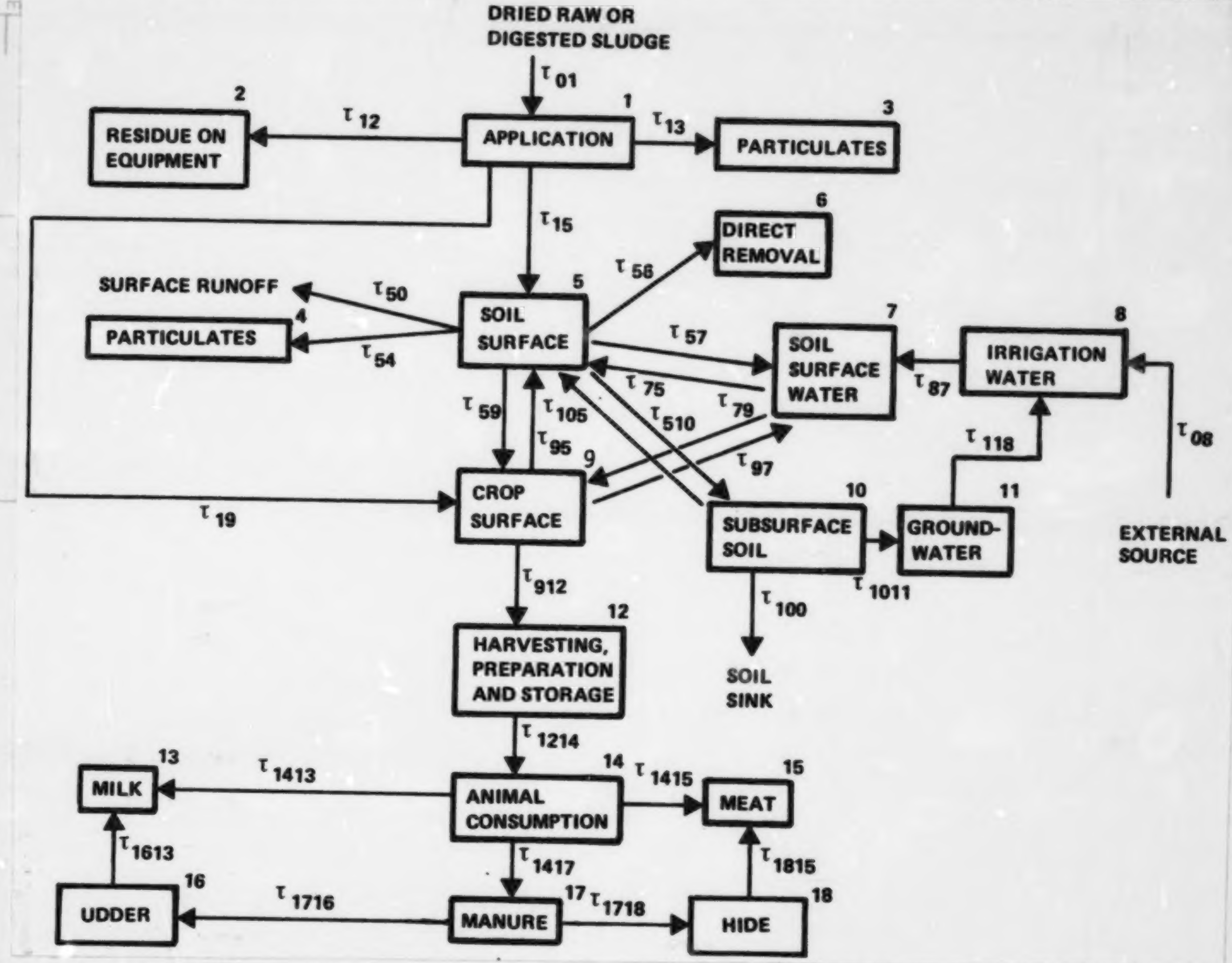
DRIED RAW OR DIGESTED SLUDGE
τ 01
1 APPLICATION
2 RESIDUE ON EQUIPMENT
τ 12
τ 13
3 PARTICULATES
τ 15
6 DIRECT REMOVAL
τ 56
SURFACE RUNOFF
τ 50
4 PARTICULATES
τ 54
5 SOIL SURFACE
τ 57
7 SOIL SURFACE WATER
τ 87
8 IRRIGATION WATER
τ 75
τ 79
τ 510
τ 59
τ 105
τ 95
τ 97
τ 118
τ 08
EXTERNAL SOURCE
9 CROP SURFACE
τ 19
10 SUBSURFACE SOIL
11 GROUND-WATER
τ 1011
τ 100
SOIL SINK
τ 912
12 HARVESTING, PREPARATION AND STORAGE
τ 1214
14 ANIMAL CONSUMPTION
13 MILK
τ 1413
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15 MEAT
τ 1613
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16 UDDER
τ 1716
17 MANURE
τ 1718
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Figure 6. Sludge Application Pathway - Fertilizer for Crops That Are Processed Prior to Animal Consumption

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TABLE 6a. DIFFERENTIAL EQUATIONS FOR PATHWAY 6

SLUDGE APPLICATION PATHWAY - FERTILIZER FOR CROPS THAT ARE PROCESSED PRIOR TO ANIMAL CONSUMPTION

$$\dot{N}_{1} = \tau_{01} - \tau_{12} - \tau_{13} - \tau_{15} - \tau_{19} - \rho_{1}$$

$$\dot{N}_{2} = \tau_{12} + \rho_{2}$$

$$\dot{N}_{3} = \tau_{13} + \rho_{3}$$

$$\dot{N}_{4} = \tau_{54} + \rho_{4}$$

$$\dot{N}_{5} = \tau_{15} + \tau_{75} + \tau_{95} + \tau_{105} - \tau_{50} - \tau_{54} - \tau_{56} - \tau_{57} - \tau_{59} - \tau_{510} + \rho_{5}$$

$$\dot{N}_{6} = \tau_{56} + \rho_{6}$$

$$\dot{N}_{7} = \tau_{57} + \tau_{87} + \tau_{97} - \tau_{75} - \tau_{79} + \rho_{7}$$

$$\dot{N}_{8} = \tau_{08} + \tau_{118} - \tau_{87} + \rho_{8}$$

$$\dot{N}_{9} = \tau_{19} + \tau_{59} + \tau_{79} - \tau_{95} - \tau_{97} - \tau_{912} + \rho_{9}$$

$$\dot{N}_{10} = \tau_{510} - \tau_{100} - \tau_{105} - \tau_{1011} + \rho_{10}$$

$$\dot{N}_{11} = \tau_{1011} - \tau_{118} + \rho_{11}$$

$$\dot{N}_{12} = \tau_{912} - \tau_{1214} + \rho_{12}$$

$$\dot{N}_{13} = \tau_{1413} + \tau_{1613} + \rho_{13}$$

$$\dot{N}_{14} = \tau_{1214} - \tau_{1413} - \tau_{1415} - \tau_{1417} + \rho_{14}$$

$$\dot{N}_{15} = \tau_{1415} + \tau_{1815} + \rho_{15}$$

$$\dot{N}_{16} = \tau_{1716} - \tau_{1613} + \rho_{16}$$

$$\dot{N}_{17} = \tau_{1417} - \tau_{1716} - \tau_{1718} + \rho_{17}$$

$$\dot{N}_{18} = \tau_{1718} - \tau_{1815} + \rho_{18}$$

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TABLE 6b. VARIABLES FOR PATHWAY 6

SLUDGE APPLICATION PATHWAY - FERTILIZER FOR CROPS THAT ARE PROCESSED PRIOR TO ANIMAL CONSUMPTION

POSITION	DEFAULT VALUES	VARIABLE	DEFINITION
		INPUT VARIABLES	
1	1.95E+7 4.95E+2 6.25E+7	ASCRS	Number of pathogens per kilogram of applied sludge.
2	5.607E+3	APRATE	Application rate of sludge in kilograms per hectare.
3	ASCRS*APRATE	ASCIN	Total number of pathogens entering pathway. If present, overrides first two variables.
4	10.	WTRES2	Dry weight in kilograms of sludge left as residue on equipment used for Application.
5	1.5	WTPAR3	Dry weight in kilograms of particulates generated by sludge Application.
6	0.7	TASS	Fraction of transfer from Application to Soil Surface.
7	-2.	TRAIN	Time in hours of arbitrary rain. (If -2., there is no rain.)
8	0.1 0.05 0.1	FRAIN	Fraction of total pathogens transferred from Soil Surface to Surface Runoff by rain.
9	720.	TCUT	Time of cutting of crop in hours.
10	0.5	WTPAR4	Weight in kilograms of particulates generated from Soil Surface by crop cutting.
11	0.1 0.05 0.1	SSTSSW	Fraction of transfer from Soil Surface to Soil Surface Water.

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TABLE 6b. (continued)

POSITION	DEFAULT VALUES	VARIABLE	DEFINITION
12	0.25	WTCSUR	Weight in kilograms of transfer from Soil Surface to Crop Surface.
13	0.001 0.0 0.83	SSTSSS	Fraction of transfer from Soil Surface to Subsurface Soil.
14	0.0125	WTDRMV	Dry weight in kilograms of transfer from Soil Surface to Direct Removal.
15	8.	DEPTH	Depth of irrigation water applied in centimeters.
16	2.	FILTR8	Infiltration rate of Soil Surface Water into the soil in centimeters per hour.
17	0.1 0.05 0.1	SSWTCS	Fraction of transfer from Soil Surface Water to Crop Surface.
18	0.01	CSTSS	Fraction of transfer from Crop Surface Water to Soil Surface.
19	0.0	SSSTGW	Fraction of transfer from Crop Surface Soil to Groundwater.
20	0.0	TSSTSS	Fraction of transfer from Subsurface Soil to Soil Surface.
21	1.0E-6	DILGRN	Groundwater use and dilution.
22	0.5	DILIRR	Fraction of irrigation water from Groundwater.
23	-2.	TCULT	Time of cultivation in hours. (If -2., there is no cultivation.)
24	0.0	COUNT	Number of pathogens introduced into irrigation water from External Source (total population).

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TABLE 6b. (continued)

POSITION	DEFAULT VALUES	VARIABLE	DEFINITION
25	0.5	CSSSW	Fraction of transfer from Crop Surface to Soil Surface Water.
26	720.	STORAG	Duration of storage in Compartment 12 in hours.
27	30.	ALFALF	Percent of feed which is harvested crop.
28	30.	COWS	Number of days each cow is fed harvested crop.
29	20.	TEMP	Ambient temperature throughout pathway in degrees Celsius.
30	-1.	COW	Animal type: -1. = meat cow +1. = milk cow.
31	0.001	MANHID	Fraction of transfer from Manure to Hide.
32	0.0005	MANUDR	Fraction of transfer from Manure to Udder.
33	0.5	UDRMLK	Fraction of transfer from Udder to Milk.
34	-2.	TSLOTR	Time of slaughter in days. Slaughter will occur at time of maximum population levels on the day specified. Selecting slaughter defines herd as meat cows. (If -2., there is no slaughter.)
35	0.1	FRSLOT	Fraction of transfer from Hide to Meat at slaughter.
36	0.0	DTCTMT	Fraction of transfer from Animal Consumption to Meat.
37	0.0	DTCTMK	Fraction of transfer from Animal Consumption to Milk.

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TABLE 6b. (concluded)

OUTPUT VARIABLES

38	(output)	TIRRG	Time elapsed since irrigation.
39	(output)	SAVE	Pathogens transferred to Compartment 6.
40	(output)	TCONSP	Time of consumption.
41	(output)	CONSUM	Pathogens consumed per cow per day.

NOTES: The number of pathogens per day entering the pathway will default to APRATE*ASCRS if no value is specified for ASCIN. If a value is specified for ASCIN, it will override the APRATE*ASCRS value.

Whenever three default values are specified for any variable in the list above, the order is salmonellae, ascaris, poliovirus pathogen types. The appropriate default value will be selected to agree with the pathogen type being considered in a particular run.

All units of measure are in kilograms, degrees Celsius, or hours unless otherwise stated.

Variables labeled "output" are for internal computations and are not available to the user as input.

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c. The amount of sludge applied to the field (APRATE) and the concentration of pathogens in that sludge (ASCRS) are user-specifiable variables. Default values are based on adding 67 metric tons of sludge per hectare to the field each year (48). One-twelfth of this amount is applied at the start of each pathway run. The default values for the number of pathogens present in the sludge reflect a conservative "worst case" and are set equal to the concentration of each pathogen in raw sludge from a municipal treatment system (1,4,28,32,77). The value of output variable PTOTL, position 20 of Pathway 1's P-array, is equal to the number of pathogens per kilogram of sludge at the end of a run of Pathway 1. The user may run Pathway 1 for one of the three pathogens and then use the output value of PTOTL as the value for ASCRS, the variable in position 1 of Pathway 6's P-array. ASCRS determines the number of pathogens per kilogram of sludge applied to the field as fertilizer. In this way Pathways 1 and 6 may be linked and a selected pathogen followed through treatment and application of sludge.

d. The field is 1 hectare in size and will produce 1000 kilograms of dry matter per cutting (3).

e. At the time of application, sludge is chain harrowed to distribute it evenly over the entire field. A fraction of the applied sludge is knocked to the surface soil while a fraction clings to crop surface. The user may specify this distribution using the variable TASS. Surface soil is defined as the first 10 centimeters of soil. This zone is affected by changing temperatures and dries after each irrigation. Below the surface soil is the subsurface soil which extends from 10 to 80 centimeters. The depth of this zone was defined to include that soil area from which 90 percent of the water requirements of a forage crop are met (6).

f. Default values for soil factors describe a sandy loam soil. The water infiltration rate (26, 33) and water holding capacity of the soil (80) are functions of soil type and determine the duration of several compartments. Values used in the transfer of pathogens from the surface to subsurface soil zones were based upon the ability of sandy loam soils to filter and adsorb particles of different sizes carrying different charges (4, 89). Variables are provided in the model for soil factors and the fraction of transfer between pathway compartments. The user may specify values for these variables which describe other soil types.

g. The field is irrigated after the application of sludge once for each cutting cycle. The field is assumed to be flooded to a uniform depth. The irrigation water then infiltrates the soil at a constant and uniform rate. The default value for depth of irrigation water (DEPTH) is calculated to allow infiltration of

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water only 60 to 90 centimeters below the soil surface (6). This will preclude transfers to groundwater but the user may specify a deeper irrigation which would cause a transfer of pathogens from the subsurface soil to groundwater. The user would have to supply a value for SSTGW if such a transfer were desired. Infiltrating water will saturate the soil as it percolates downward until the trailing edge transverses the surface soil zone. At this time, the surface soil layer will be at a field capacity. The soil in this layer then dries at a rate calculated for sandy loam soils in the Southwest (96). The subsurface soil layer is always at field capacity.

h. The moisture content and temperature of the environment determine the growth and/or inactivation of pathogens.

i. Irrigation water may be pumped from groundwater influenced by irrigation, may be from the diversion of surface flows, or may be a combination of water from both sources. Variables included in the pathway indicate the dilution factor of pathogens present in groundwater (DILGRN) and the fraction of the total irrigation from this source (DILIRR). The number of pathogens from an external source (COUNT) can be specified.

j. An optional rain is included in the pathway. If requested, the rain will produce surface runoff which removes a fraction of surface-soil-associated with pathogens. The values incorporated in the model for intensity and duration of rainfall result in 1/2 inch of rain falling on the field in 24 hours. This produces a moderate runoff calculated as one-fourth the peak discharge for a sandy loam soil covered by grass (14).

k. Workers enter the field once during each week of the cutting cycle to check soil moisture and crop growth. They are in direct contact with both the surface soil and crop surface and remove soil and sludge which stick to shoes, clothing, and skin. Default values for direct removal specified in variable WTDRMV are estimates of contact. The user may supply values which reflect his own experience.

l. Particulates generated during sludge application and at TCUT (the time when the crop is harvested) are assumed to be at a level of 15 milligrams of sludge-fertilized soil per cubic meter of air in a volume extending 10 meters above the area of the field.

m. At the end of a cutting cycle (time set by TCUT) the crop is cut and allowed to field dry for 7 days to a moisture content of 20 percent (6) before being baled. The crop is then stored (time set by STORAG) before being used as a feed.

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n. The dried crop is fed to cows which consume 7 kilograms of feed each day (66). The feed is approximately 30 percent crop. The user may vary the percent of sewage-sludge-exposed crop fed to the cattle and the length of time each cow is fed on the prescribed diet by specifying the values of ALFALF and COWS, respectively. One cutting of the crop will feed 12 cows for 1 month when default values are used.

o. Each cow will eliminate 10 kilograms of manure at 80 percent moisture each day (40, 60). Manure for the entire herd will be deposited at one time each day to simplify process functions. Manure is assumed to dry at a rate which is based on sludge evaporation (10).

p. The user must decide before each pathway run if the cattle being fed the crop are a dairy herd and milked or are a beef herd and slaughtered for meat. If the dairy option (this is the default condition) is selected, cows are milked twice a day at 12-hour intervals. Each cow will deliver 15 liters of milk at each milking (65). The milk is stored at 4°C regardless of the ambient temperature selected for a model run. The total growth of salmonella in milk is limited to 1×10^{12} per liter. If the beef herd option is selected (by setting the variable COW to -1.), a fraction of the manure which contacts hide will be transferred to meat during slaughter (91). Each cow yields 270 kilograms of meat (53).

q. Salmonella infections in cattle can be systemic (13). Transfers of pathogens directly from the cow to milk and meat are included in the pathway (TA1413 and TA1415, respectively). Because infections of adult cattle are usually nonsymptomatic and localized in the mesenteric lymph nodes (5), default values for the fraction of transfer directly to milk and meat (variables DTCTMK and DTCTMT, respectively) are zero for all pathogens. Infections in cattle are assumed to occur whenever the total consumption of salmonella exceeds 1×10^9 cells per day. In the event of infection, the number excreted per cow per day in manure is increased to 1×10^{12}. Cows cannot be infected by poliovirus or ascaris ova (ascaris in this model always refers to Ascaris lumbricoides). Both are assumed to be unaffected by herbivore digestion and to be excreted in the same numbers as ingested. Milk and meat can be contaminated by contact with manure. All three pathogens can be transferred by this route.

Compartment Descriptions

Compartment 1, APPLICATION --

Sludge is applied to a 1-hectare field planted in a forage crop. The amount is determined by the variable APRATE and the pathogen population by the variable ASCRS. The sludge-covered field is then chain harrowed, an operation which spreads the sludge evenly over the whole field and knocks some of it from the forage-crop surface to the soil surface. At the end of APPLICATION the applied sludge is distributed between Compartment 5, SOIL SURFACE, and Compartment 9, CROP SURFACE. The user may determine the division of sludge between these two compartments by specifying a value for the variable TASS. This variable specifies the percentage of the total pathogen population in applied sludge that reaches the SOIL SURFACE. The remaining sludge is assumed to cling to the forage CROP SURFACE. The default value for TASS is an estimate.

There are four transfers out of this compartment. During the spreading of sludge and the subsequent harrowing operations dust is generated. This is simulated by a transfer of sludge-associated pathogens by TAU13 to Compartment 3, PARTICULATES. The amount of sludge transferred is divided by the weight of sludge applied (APRATE) and is then multiplied by the number of pathogens in Compartment 1 to determine the number of pathogens transferred to PARTICULATES. This transfer occurs 2 hours into the pathway.

Sludge adheres to spreading and harrowing equipment. A weight of sludge specified by the variable WTRES2 is transferred to Compartment 2, RESIDUE, by TAU12. The number of pathogens associated with the transferred sludge is calculated in the same manner as the particulate-associated pathogens above. This transfer occurs 3 hours into the pathway.

At the end of activities for this compartment the transfers are made to Compartment 5, SOIL SURFACE, and to Compartment 9, CROP SURFACE, by TAU15 and TAU19, respectively.

Time of first transfer into compartment - Start of pathway.

Time of last transfer out of compartment - 3 hours into pathway.

Process function - RH01
  Activated: Start of pathway.
  Duration: 3 hours.
  Rates: Salmonella: 0.0 * N(1)/hour.
    Ascaris: 0.0 * N(1)/hour.
    Poliovirus: 0.0 * N(1)/hour.

Transfers into compartment -
  TAU01 = ASCIN, Transfer occurs at start of pathway.

Transfers out of compartment -
  TAU12 = (WTRES2/(APRATE - WTPAR3))*N(1), Transfer occurs 3 hours into pathway.
  TAU13 = (WTPAR3/APRATE)*N(1), Transfer occurs 2 hours into pathway.
  TAU15 = TASS*(N(1) - TAU12 + TAU13), Transfer occurs at 3 hours into pathway.
  TAU19 = (1. - TASS)*(N(1) - (TAU12 + TAU13)), Transfer occurs 3 hours into pathway.

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Compartment 2, RESIDUE ON EQUIPMENT --

RESIDUE is left on equipment at the end of the APPLICATION compartment. The amount is determined by the variable WTRES2. The default value for this variable is an estimate. The material in RESIDUE compartments is assumed to dry out rapidly. The process functions assigned to this and other RESIDUE compartments reflect the effects of desiccation on the model pathogens.

Time of first transfer into compartment - 3 hours into pathway.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RH02

Activated:	3 hours into pathway.	
Duration:	Until all pathogens are depleted or the pathway ends.	
Rates:	Salmonella:	-0.46*N(2)/hour. (8) The inactivation of a residue-associated salmonella is assumed to occur at the rate of salmonella in drying sludge at greater than 80 percent solids.
	Ascaris:	-0.25*N(2)/hour. (22, 40, 74)
	Poliovirus:	-0.37*N(2)/hour. (88, 97)

Transfers into compartment -
TAU12 = (WTRES2/(APRATE - WTPAR3))*N(1), Transfer occurs 3 hours into pathway.

Transfers out of compartment - None.

Compartment 3, PARTICULATES --

The activities described for Compartment 1 will generate airborne dust or PARTICULATES. It is assumed in all PARTICULATE compartments that the dust is generated at the start of activities in the compartment from which the transfer to PARTICULATES is made, in this case Compartment 1 - APPLICATION, and that the dust and its associated pathogens remain at the initial concentration until the generating activity ceases. The process functions in all PARTICULATES compartments are delayed to allow for maximum inhalation of pathogens during generation activities.

The user may specify the amount of sludge being transferred to this compartment by assigning a value to WTPAR3. There are two compartments described by the title PARTICULATES in this pathway: Compartment 3 and Compartment 4. To avoid confusion in this and other pathways, a naming system was used in which the "weight transferred to PARTICULATES" is abbreviated "WTPAR" and the number of the compartment concerned is appended. Thus, WTPAR3 represents the weight of sludge transferred to PARTICULATES in Compartment 3.

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The default value assigned WTPAR3 was determined by assuming that PARTICULATES are generated to a level of 15 mg/m^3 in a volume extending 10 meters over the 1-hectare field. The concentration of particulates and the height of the volume considered are the same in all PARTICULATES compartments but the area under the dust cloud differs between pathways.

The process functions for PARTICULATES are the same as for RESIDUE and reflect the effects of rapid desiccation on the airborne material and the pathogens associated with it.

Time of first transfer into compartment - 2 hours into pathway.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RHO3
Activated: 4 hours into pathway.
Duration: Until all pathogens are depleted or the pathway ends.
Rates: Salmonella: -0.46*N(3)/hour. (8)
Ascaris: -0.25*N(3)/hour. (22, 40, 74)
Poliovirus: -0.38*N(3)/hour. (88, 97)

Transfers into compartment -
TAU13 = (WTPAR3/APRATE)*N(1), Transfer occurs 2 hours into pathway.

Transfers out of compartment - None.

Compartment 4, PARTICULATES --
The PARTICULATES generated in this compartment represent the dust raised during crop cutting. The dust blown up from the SOIL SURFACE is simulated by transfer TAU54. The amount of sludge-amended soil involved is specified by assigning a value to WTPAR4. The default value for this variable assumes that 15 milligrams of dust are generated for each cubic meter of air in a 10-meter high volume above the 1-hectare field. The process functions for this compartment are delayed 12 hours to provide for maximum inhalation by workers.

Time of first transfer into compartment - TCUT

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RHO4
Activated: TCUT + 12 hours.
Duration: Until all pathogens are depleted or the pathway ends.

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Rates: Salmonella: -0.46*N(4)/hour. (8)
Ascaris: -0.25*N(4)/hour. (22, 40, 74)
Poliovirus: -0.38*N(4)/hour. (88, 97)

Transfers into compartment -
TAU54 = WTPAR4/(TASS*(APRATE - WTRES2 - WTPAR3))*N(5), Transfer occurs at TCUT.

Transfers out of compartment - None.

Compartment 5, SOIL SURFACE --
The first 10 centimeters of soil comprise the SOIL SURFACE. The soil in this compartment is subjected to a moisture cycle which begins 24 hours into the pathway with the irrigation of the field. The soil is at field capacity (20 percent weight/weight) after irrigation and dries to the wilting point (4 percent weight/weight). Pathogen process functions are tied to the irrigation cycle. The rate of growth or inactivation of pathogens is dependent on the ambient temperature of the environment and on the available water. The ambient temperature is constant throughout the pathway and is set by the variable TEMP. The available water is a function of the time elapsed since irrigation.

Sludge fertilizer and pathogens are first transferred into this compartment from the APPLICATION compartment by TAU15. As the pathway progresses there are several other transfers into this compartment. At irrigation, water from Compartment 8, IRRIGATION WATER, is transferred to Compartment 7, SOIL SURFACE WATER. This water then percolates into the soil, transferring pathogens to SOIL SURFACE by TAU75. The pathogens involved in this transfer may be either soil pathogens which become suspended in the water during irrigation, a phenomenon simulated by TAU57, or may be pathogens introduced with the irrigation water itself. In a similar manner, after pathogens have been transferred to CROP SURFACE, some will be transferred to SOIL SURFACE by TAU95 when gravity and wind cause dust and sludge to fall to the ground. If the field is cultivated after planting, pathogens which have been carried to SUBSURFACE SOIL (Compartment 10) will be transferred to the SOIL SURFACE as the ground is turned. This is simulated by TAU105.

There is one other way for pathogens to enter this compartment. The user may place an initial pathogen population in any pathway compartment by specifying the compartment number and the desired population in the POPL variable of the $ARGS name list. The mechanism for handling variable specification is fully described in the user's manual for the program (Appendix A). Specifying an initial pathogen population allows the user to examine the effects of several sludge applications. The final compartment populations of one model run would be input as initial populations in the next run. Environmental conditions may be unique for each run, or standard default values may be used.

Pathogens are transferred from this compartment into Compartment 4, PARTICULATES, by TAU54; Compartment 9, CROP SURFACE, by TAU59; Compartment

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10, SUBSURFACE SOIL, by TAU510; Compartment 7, SOIL SURFACE WATER, by TAU57; Compartment 6, DIRECT REMOVAL, by TAU56; and to SURFACE RUNOFF by TAU50. PARTICULATES are generated by crop cutting which occurs at time TCUT. The transfer from SOIL SURFACE to SUBSURFACE SOIL occurs after irrigation as irrigation water percolates below the 10-centimeter mark which separates SOIL SURFACE from SUBSURFACE SOIL. The time of this transfer is controlled by the infiltration rate of SOIL SURFACE WATER, a parameter the user may specify in variable FILTR8. The infiltrating water carries pathogens with it. The fraction of the total population in SOIL SURFACE transferred by percolating water to SUBSURFACE SOIL is specified in the variable SSTSSS. The default values for this variable are estimates that take into account the size and soil-binding capacities of each pathogen.

Pathogens associated with SOIL SURFACE are suspended in irrigation water while it is lying on the surface of the field and is considered to be in Compartment 7, SOIL SURFACE WATER. This transfer occurs at irrigation. The fraction of total SOIL SURFACE pathogens suspended in SOIL SURFACE WATER is determined by the variable SSTSSW. These pathogens and any introduced from IRRIGATION WATER are transferred to SOIL SURFACE by TAU75 when the irrigation water percolates into the soil. Soil and pathogens are transferred to CROP SURFACE constantly as dust is blown up from the SOIL SURFACE. The weight of each transfer is determined by WTCSUR. Workers will enter the field weekly to inspect the crop. They will carry dirt away with them on hands, shoes, and clothing. This DIRECT REMOVAL may be quantified in the variable WTDRMV.

The transfer to SURFACE RUNOFF simulates the effects of rain and occurs at TRAIN. SURFACE RUNOFF is not a compartment because the scope of this model is not large enough to follow pathogens beyond the 1 hectare which constitutes the field. SURFACE RUNOFF by definition leaves the field. The rain which produces runoff is an arbitrary event which does not occur under default conditions. The user must set TRAIN to a positive number for rain to occur. The number will equal the time in hours when the rain occurs. The user may also control the number of pathogens washed from the SOIL SURFACE and removed from the pathway by TAU50 by specifying the value of FRAIN.

Time of first transfer into compartment - 3 hours into pathway.

Time of last transfer out of compartment - End of pathway.

Process function - RHO5
    Activated: 4 hours into pathway.
    Duration: Until the end of the pathway.
    Rates: Salmonella: 0.070*N(5)/hour, for $20 \le TEMP < 45$ and $0 < TIRRG \le 3.5$ days. The growth of salmonella is assumed to occur at one-half the rate for *E.coli* in the sterile compost. (62)

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-0.012*N(5)/hour, for 20 ≤ TEMP < 45 and 3.5 < TIRRG ≤ 5.5 days. (23, 72, 73)
-0.46*N(5)/hour, for TEMP < 45 and 5.5 < TIRRG < 7 days. (8)
-3.45*N(5)/hour, for TEMP ≥ 45 and any time. (8, 93)
0.0*N(5)/hour, for TEMP < 20 and any time. No changes in pathogen population are assumed for temperatures less than 20°C.

Ascaris:
-0.0005*N(5)/hour, for TEMP < 40 and 8 hours < TIRRG ≤ 5.5 days. (83)
-1.54*N(5)/hour, for 40 ≤ TEMP ≤ 50 and 8 hours < TIRRG ≤ 5.5 days. (7, 78)
-0.25*N(5)/hour, for TIRRG > 5.5 days and any temperature. (22, 40, 74)

Poliovirus:
-0.005*N(5)/hour, for 15 < TEMP < 45 and 8 hours < TIRRG ≤ 6.5 days. (96)
-0.027*N(5)/hour, for TEMP < 45 and TIRRG > 6.5 days. (87, 96)
-0.38*N(5)/hour, for TEMP ≥ 45 and any time. (88, 97)
-0.00087*N(5)/hour, for TEMP < 15 and 8 hours < TIRRG < 6.5 days. (96)

Transfers into compartment -
TAU15 = TASS*(N(1) - (TAU12 + TAU13)), Transfer occurs 3 hours into pathway.
TAU75 = N(7) - TAU79, Transfer occurs at 24 hours + DEPTH/FILTR8.
TAU95 = (CSTSS/24.)*N(9), Transfer occurs hourly from 24 hours.
TAU105 = TSSTSS*N(10), Transfer occurs at TCULT if TCULT ≥ 1.

Transfers out of compartment -
TAU50 = (FRAIN*N(5)*0.17), Transfer occurs at TRAIN if TRAIN ≥ 1.
TAU54 = (WTPAR4/(TASS*(APRATE - WTRES2 - WTPAR3)))*N(5), Transfer occurs at TCUT.
TAU56 = (WTDRMV/(APRATE - WTRES2 - WTPAR3))*N(5), Transfer occurs weekly after 4 hours into the pathway.
TAU57 = SSTSSW*N(5), Transfer at irrigation (24 hours into pathway).
TAU59 = (WTCSUR/(TASS*(APRATE - WTRES2 - WTPAR3)))/24.*N(5), Transfer occurs each hour.
TAU510 = SSTSSS*N(5), Transfer occurs at 24 hours + DEPTH/FILTR8.

Compartment 6, DIRECT REMOVAL --

Surface soil and the pathogens associated with it will adhere to the shoes, clothing, and skin of people who enter the field. These pathogens are directly removed from the field. This transfer occurs weekly.

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Pathogen populations transferred into this compartment are reduced linearly to zero over a 24-hour period.

Time of first transfer into compartment - 4 hours into pathway.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of this compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RH06
Activated: 4 hours into pathway.
Duration: Until all pathogens are depleted or the pathway ends.
Rates: Salmonella: -N(6)/24./hour.
Ascaris: -N(6)/24./hour.
Poliovirus: -N(6)/24./hour.

Transfers into compartment -
TAU56 = (WTDRMV/(APRATE - WTRES2 - WTPAR3))*N(5), Transfer occurs at weekly intervals

Transfers out of compartment - None.

Compartment 7, SOIL SURFACE WATER --
Irrigation in this model involves flooding the field with water to a uniform depth (specified by the variable DEPTH) and then allowing the water to infiltrate the soil at a constant rate (specified by the variable FILTR8). The water transfers into SOIL SURFACE WATER from Compartment 8, IRRIGATION WATER, by TAU87 and may carry with it a pathogen load. Pathogens in SOIL SURFACE and on the CROP SURFACE will become suspended in the overlying water. These transfers from Compartment 5 and Compartment 9, respectively, will occur at irrigation (24 hours into the pathway).

Pathogens transfer back to Compartment 5, SOIL SURFACE, and Compartment 6, CROP SURFACE, when the irrigation water soaks into the soil. While this would normally be a gradual process, TAU85 and TAU86 occur at the end of irrigation as a single transfer to each compartment.

Time of first transfer into compartment - 24 hours into pathway.

Time of last transfer out of compartment - 24 hours + (DEPTH/FILTR8).

Process function - RH07
Activated: 24 hours into pathway.
Duration: DEPTH/FILTR8.
Rates: Salmonella: 0.23*N(7)/hour.
A 3-hour generation time is assumed for growth of salmonella suspended in irrigation water.
Ascaris: 0.0*N(7)/hour.

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Poliovirus: 0.0*N(7)/hour.
No change is assumed for ascaris and poliovirus suspended in irrigation water.

Transfers into compartment -
TAU57 = SSTSSW*N(5), Transfer occurs at irrigation.
TAU87 = N(8), Transfer occurs at irrigation.
TAU97 = CSSSW*N(9), Transfer occurs at irrigation and at TRAIN.

Transfers out of compartment -
TAU75 = N(7) - TAU79, Transfer occurs at (DEPTH/FILTR8).
TAU79 = SSWTCS*N(7), Transfer occurs after irrigation at (DEPTH/FILTR8).

Compartment 8, IRRIGATION WATER--

In this compartment water from two sources is combined. Water is transferred into the compartment from GROUNDWATER by TAU118 and from an EXTERNAL SOURCE by TAU08. GROUNDWATER represents well water used here for irrigation. It may contain pathogens which have been carried through SUBSURFACE SOIL by deep percolation (TA1011). EXTERNAL SOURCE represents surface flows used for irrigation. This water may also contain pathogens. The user may specify the level of contamination by assigning a value to the variable COUNT. The ratio of GROUNDWATER to EXTERNAL SOURCE water is determined by the variable DILIRR.

EXTERNAL SOURCE is not defined as a pathway compartment since it is beyond the scope of this model to consider water pollution other than the possible additive effects of using contaminated water on a sludge-fertilized field. The IRRIGATION WATER compartment has a very short duration and no process functions have been defined. The compartment does not represent a physical part of the environment but rather the transition between several states. As soon as the waters are mixed they become SOIL SURFACE WATER, represented by Compartment 7. This transfer is accomplished by TAU87.

Time of first transfer into compartment - 23 hours into pathway.

Time of last transfer out of compartment - 24 hours into pathway.

Process function - RHO8
Activated: 24 hours into pathway.
Duration: 1 hour.
Rates: Salmonella: 0.0*N(8)/hour.
Ascaris: 0.0*N(8)/hour.
Poliovirus: 0.0*N(8)/hour.

Transfers into compartment -
TAU08 = COUNT, Transfer occurs 23 hours into the pathway.
TAU118 = DILGRN*DILIRR*N(11), Transfer occurs 23 hours into the pathway.

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Transfers out of compartment -
TAU87 = N(8), Transfer occurs at irrigation, 24 hours into pathway.

Compartment 9, CROP SURFACE --

In a field with a standing crop, a fraction of the sludge applied would land on the CROP SURFACE, a transfer shown by TAU19. The user can control the distribution of sludge between Compartment 5, SOIL SURFACE, and this compartment by specifying the value of TASS. As the pathway progresses there are several other transfers into this compartment. Each day dust is blown up from SOIL SURFACE. Some of it (an amount specified by WTCSUR) will cling to the CROP SURFACE. This transfer, TAU59, occurs daily. The crop is washed by irrigation water 24 hours into the pathway. As the water soaks into the soil a fraction of the pathogens in Compartment 7, SOIL SURFACE WATER, are transferred by TAU79 to CROP SURFACE. This transfer is determined by the variable SSWTCS.

Pathogens can be transferred from this compartment back to Compartment 5, SOIL SURFACE, as dust and leaves fall to the ground. TAU95 is a continuing transfer throughout the pathway, with a fraction of the total population of Compartment 9, specified by variable CSTSS, transferred each hour. During irrigation, a fraction of the total population (variable CSSSW is calculated to be that part associated with water-covered foliage when the irrigation depth is 15.2 cm (6 inches)) is suspended in SOIL SURFACE WATER. This transfer is designated TAU97. At TCUT the crop is cut and the pathogen population associated with the crop is transferred to Compartment 12 - HARVESTING, PREPARATION and STORAGE.

Time of first transfer into compartment - 3 hours into pathway.

Time of last transfer out of compartment - TCUT.

Process function - RHO9
Activated: 3 hours into pathway.
Duration: The duration of the compartment is a variable determined by the value of TCUT.
Rates: Salmonella: -0.096*N(9)/hour. (72, 73)
Ascaris: -1.54*N(9)/hour. (7, 78)
Poliovirus: -0.069*N(9)/hour. (49)

Transfers into compartment -
TAU19 = (1. - TASS)*(N(1) - (TAU12 + TAU13)), Transfer occurs 3 hours into pathway.
TAU59 = (WTCSUR/(TASS*(APRATE - WTRES2 - WTPAR3)))/24.*N(5), Transfer occurs once each hour from 3 hours.
TAU79 = SSWTCS*N(7), Transfer occurs after irrigation at 24 hours + (DEPTH/FILTR8).

Transfers out of compartment -
TAU95 = CSTSS/(24.*N(9)), Transfer occurs every hour.

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TAU97 = CSSSW*N(5), Transfer occurs at irrigation, 24 hours into pathway and at TRAIN.
TAU912 = N(9), Transfer occurs at TCUT.

Compartment 10, SUBSURFACE SOIL --

This compartment represents the soil from 10 to 80 centimeters below the surface. This SUBSURFACE SOIL is at constant moisture (field capacity, 20 percent weight/weight) and temperature (15°C). Pathogens from the sludge-fertilized upper 10 centimeters of soil are transferred into this compartment with percolating irrigation water. The fraction of the total SOIL SURFACE (Compartment 5) pathogen population transferred is determined by the variable SSTSSS. The time of the transfer by TAU510 is controlled by the depth of irrigation water which must soak in (DEPTH) and the rate of water infiltration (FILTR8). The transfer occurs after irrigation.

There are three possible transfers out of this compartment. Pathogens may be transferred to Compartment 11, GROUNDWATER, by TA1011. The variable, SSTGW, which specifies the fraction of total SUBSURFACE SOIL pathogens transferred is set to zero under default conditions. The 6 centimeters of applied irrigation water specified by default values would only penetrate to 60 centimeters, precluding transfer to GROUNDWATER. The user should specify a value for SSSTGW if DEPTH is set to more than 6 centimeters.

Pathogens may be transferred to Compartment 5, SOIL SURFACE, by TAU105 if the user specifies a positive value for the variable TCULT. This variable indicates that cultivation is to be simulated and sets the time at which the field will be plowed. The variable TSSTSS determines the fraction of SUBSURFACE SOIL pathogens transferred.

Pathogens which do not transfer out of this compartment in the transfers listed above are transferred to the SOIL SINK at TCUT by TAU100. The SOIL SINK is not defined as a compartment in this model.

Time of first transfer into compartment - 24 hours + (DEPTH/FILTR8).

Time of last transfer out of compartment - TCUT.

Process function - RH010
  Activated: 24 hours + (DEPTH/FILTR8).
  Duration: Until TCUT.
  Rates: Salmonella: -0.012*N(8)/hour. (23, 72, 73)
    Ascaris: -0.00053*N(8)/hour. (83)
    Poliovirus: -0.0049*N(8)/hour. (27, 96)

Transfers into compartment -
  TAU510 = SSTSSS*N(5), Transfer occurs after irrigation at 24 hours + (DEPTH/FILTR8).

Transfers out of compartment -
  TAU100 = N(10), Transfer occurs at TCUT.
  TAU105 = TSSTSS*N(10), Transfer occurs at TCUT.

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TA1011 = SSSTGW*N(10), Transfer occurs after irrigation at 24 hours + (DEPTH/FILTR8) + 1 hour.

Compartment 11, GROUNDWATER --

Pathogens applied to a field may contaminate groundwaters if surface water percolates deeply enough. The default values incorporated into the model preclude such contamination but, as explained in Compartment 7, the user may specify a transfer of pathogens to GROUNDWATER in order to model the effects of heavy irrigation.

Pathogens transferred to GROUNDWATER would slowly be inactivated as shown in the process functions listed below. Pathogens would also be dispersed throughout the aquifier. The user may determine the effects of dispersion by specifying a value for DILGRN. This variable is included in the equation for TAU118 and affects the pathogen number transferred to Compartment 8, IRRIGATION WATER. Another variable in the equation for TAU118 is DILIRR. It determines the fraction of the water used for irrigation that is from GROUNDWATER by specifying what fraction of the pathogens present will be transferred on. The default values for these variables were not chosen to model any particular situation. One-half of the water in Compartment 8 is from GROUNDWATER while the aquifier dilutes incoming percolation by 1 x 10^6 when default values are used.

Time of first transfer into compartment - After the irrigation at 24 hours + (DEPTH/FILTR8) + 1 hour.

Time of last transfer out of compartment - 23 hours into pathway.

Process function - RH011
    Activated: 25 hours + (DEPTH/FILTR8).
    Duration: Until end of pathway.
    Rates: Salmonella: -0.012*N(13)/hour. (23, 72, 73)
        Ascaris: -0.00053*N(13)/hour. (83)
        Poliovirus: -0.0119*N(13)/hour. (95)

Transfers into compartment -
    TA1011 = SSSTGW*N(10), Transfer occurs at 24 hours + (DEPTH/FILTR8) + 1 hour.

Transfers out of compartment -
    TAU118 = DILGRN*DILIRR*N(11), Transfer occurs 23 hours into pathway.

Compartment 12, HARVESTING, PREPARATION, AND STORAGE --

The crop is cut at TCUT, the user-specified time to harvest the crop. The crop then sits in the field for 7 days before being baled and stored. At the end of the storage period, specified by the variable STORAG, the crop is fed to cows for the number of days specified by the variable COWS. Process functions defined for this compartment are activated when the crop is cut and continue to affect the pathogens associated with the crop until the last portion is fed to the cows. These process functions simulate the effects of drying and the storage of dry crops on the representative pathogens.

All pathogens associated with CROP SURFACE enter this compartment by TAU912 at TCUT. Pathogens are transferred from this compartment to ANIMAL CONSUMPTION by TA1214 each day from the end of storage until all the crop is consumed. The 1000 kilograms of dry forage cut is assumed to feed 12 cows for 30 days when default values for ALFALF and COWS are used.

No preparation component is presently included in this compartment. If ensilage or another treatment is to be simulated, the process functions which would describe the treatment should be inserted into the model in this compartment.

Time of first transfer into compartment - TCUT.

Time of last transfer out of compartment - TCUT + 7 days + STORAG + COWS.

Process function - RH012
Activated: TCUT
Duration: 7 days + STORAG + COWS.
Rates: Salmonella: -0.96*N(12)/hour. (72, 73)
Ascaris: -1.54*N(12)/hour. (7, 78)
Poliovirus: -0.069*N(12)/hour. (49)

Transfers into compartment -
TAU912 = N(9), Transfer occurs at TCUT.

Transfers out of compartment -
TA1214 = N(12)/COWS, Transfer occurs at 24-hour intervals from TCUT + STORAG + 7 days.

Compartment 13, MILK --
The cows are milked twice each day when the dairy cow option is chosen (COW = +1.). This is the default condition. The MILK is kept at 4°C for 11 hours but is assumed to be removed from the pathway before the next milking. Pathogens can be transferred to MILK directly from Compartment 14, ANIMAL CONSUMPTION, by TA1413. This transfer will simulate the possible effects of a systemic salmonella infection. The user must supply a value for DTCTMK, the variable which specifies the fraction of Compartment 14 pathogens transferred. The default value for this variable is zero. Neither poliovirus nor ascaris are known to infect cattle and would not pass from the gut.

Pathogens are more readily transferred into milk by dirty utensils and careless handling. In the model these are combined as a transfer from manure-contaminated UDDER, Compartment 16. Transfer TA1613 occurs at each milking. All three pathogens can enter MILK by this route. The default

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value for UDRMLK is an estimate. There are no transfers out of this compartment but the pathogen population is used in milk-exposure risk calculations.

Time of first transfer into compartment - TCONSP + 38 hours.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathway terminates.

Process function - RH013
  Activated: TCONSP + 42 hours.
  Duration: 11 hours after each milking.
  Rates: Salmonella: 0.076*N(13)/hour to a limit of 1 x 10^{12} salmonella per milliliter of milk. Salmonella is allowed to grow at a generation time of 6 hours at 4°C.
    Ascaris: 0.0*N(13)/hour.
    Poliovirus: 0.0*N(13)/hour.
    Poliovirus and ascaris remain at the level transferred in.

6-1/2"

Transfers into compartment
  TA1413 = DTCTMK*N(14), Transfer occurs at 12-hour intervals from TCONSP + 38 hours.
  TA1613 = UDRMLK*N(16), Transfer occurs at 12-hour intervals from TCONSP + 42 hours.

9-1/8"

Transfers out of compartment - None.

Compartment 14, ANIMAL CONSUMPTION --
Default values assume that a portion of the stored sludge-fertilized crop is fed to 12 cows once a day for 30 days. This compartment represents the cows as they consume the crop and digest it. Pathogens are transferred into the compartment at 24-hour intervals from Compartment 12 - HARVESTING, PREPARATION, AND STORAGE - by TA1214. The transfers begin at TCONSP (TCUT + STORAG + 168 hours). The number of pathogens transferred each day is in proportion to the amount of time the crop is fed (COWS).

In the absence of data, it was assumed that herbivore digestive processes would not alter ingested pathogen populations. The possibility of infection by salmonella was taken into account. If the total daily transfer of pathogens into the compartment exceeds 1 x 10^9 salmonella per cow, infection is simulated by increasing the population in the compartment by three orders of magnitude and excreting this larger number in the manure. Transfers TA1413 and TA1415, from ANIMAL CONSUMPTION to MILK and MEAT, may also be used to simulate the effects of salmonella infection. While the default values for both DTCTMT and DTCTMK (the variables which specify the fraction of direct transfer of salmonella from ANIMAL CONSUMPTION to MEAT and MILK, respectively) are zero, the user may input values to indicate contamination of foodstuffs as a result of systemic infection.

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Materials which are consumed by the cows have a 2-day residence time before being excreted to MANURE by TA1417. One-half of the pathogen population of Compartment 14 is transferred to Compartment 17 each day as a discrete event.

Time of first transfer into compartment - TCONSP.

Time of last transfer out of compartment - End of pathway.

Process function - RH014
  Activated: TCONSP.
  Duration: Until the pathway ends.
  Rates: Salmonella: If CONSUM $\geq 1 \times 10^9$/cow, there is an immediate increase to 5×10^{12}/cow. If CONSUM $< 1 \times 10^9$/cow, there is no change in the population; 0.0*N(14)/hour.
    Ascaris: 0.0*N(14)/hour.
    Poliovirus: 0.0*N(14)/hour.

Transfers into compartment -
  TA1214 = N(12)/COWS, Transfer occurs at 24-hour intervals from TCUT + STORAG + 7 days.

Transfers out of compartment -
  TA1413 = DTCTMK*N(14), Transfer occurs at 12-hour intervals from TCONSP + 38 hours.
  TA1415 = DTCTMT*N(14), Transfer occurs at 24-hour intervals from TCONSP + 38 hours.
  TA1417 = N(14)/2., Transfer occurs at 24-hour intervals from TCONSP + 40 hours.

Compartment 15, MEAT --

If the beef cow option is chosen (the variable COW is set by the user to -1.), the cows feeding on sludge-fertilized feed will be slaughtered at TSLOTR. Slaughter will occur when pathogen levels in the cows are highest on the day assigned to TSLOTR. At slaughter, the cows become 3240 kilograms of MEAT (12 cows x 270 kilograms per cow). Pathogens can be transferred to MEAT by two routes. Salmonella can infect a cow. TA1415 simulates the direct transfer of pathogens from ANIMAL CONSUMPTION, Compartment 14 to MEAT. The default value for DTCTMT is zero since no data could be found quantifying the contamination of meat from a systemic salmonella infection and neither ascaris nor poliovirus should transfer from the gut of the cow. The user can assign a value to DTCTMT if contamination of MEAT by a systemic infection is desired. This transfer would occur daily but only for salmonella pathogen type.

When cattle are butchered, the MEAT is often contaminated by enteric bacteria. The model shows this transfer as being between the manure-contaminated HIDE and the MEAT. TA1815 will occur at TSLOTR. Default values for FRSLOT, the fraction of HIDE pathogens transferred to MEAT, are available for all three pathogen types. These are, of course, estimates. MEAT

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is assumed to be kept at 4°C following slaughter. There are no transfers out of this compartment but the pathogen population is used in meat-exposure risk calculations.

Time of first transfer into compartment - TCONSP + 38 hours.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathway terminates.

Process function - RH015
Activated: TSLOTR.
Duration: Until the pathway ends.
Rates: Salmonella: 0.076*N(15)/hour to an upper limit of 1 x 10^9 salmonella per kilogram of meat. Salmonella is allowed to grow at a generation time of 6 hours at 4°C.
Ascaris: 0.0*N(15)/hour.
Poliovirus: 0.0*N(15)/hour. Poliovirus and ascaris remain at the level transferred at slaughter.

6-1/2"

Transfers into compartment -
TA1415 = DTCTMT*N(10), Transfer occurs at 12-hour intervals from TCONSP + 38 hours.
TA1815 = FRSLOT*N(18), Transfer occurs at TSLOTR.

9-1/8"

Transfers out of compartment - None.

Compartment 16, UDDER --

This compartment provides for an indirect transfer of MANURE-associated pathogens to MILK. Pathogens are transferred from Compartment 17, MANURE, to UDDER by TA1716 once each day. The number transferred is controlled by the variable MANUDR. If the dairy cow option is selected (COW = +1.), a fraction of the pathogens on UDDER will be transferred to MILK during each milking. This fraction is specified by the variable UDRMLK. Pathogens transferred into this compartment are unaffected by process functions for 24 hours, at which time the population is reduced to zero.

Time of first transfer into compartment - TCONSP + 41 hours.

Time of last transfer out of compartment - End of the pathway.

Process function - RH016
Activated: TCONSP + 66 hours and then every 24 hours.
Duration: 1 hour for each 24-hour cycle.
Rates: Salmonella: N(16) = 0.0.
Ascaris: N(16) = 0.0.
Poliovirus: N(16) = 0.0.

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Transfers into compartment -
TA1716 = MANUDR*N(17), Transfer occurs at 24-hour intervals from TCONSP + 41 hours.

Transfers out of compartment -
TA1613 = UDRMLK*N(16), Transfer occurs at 12-hour intervals from TCONSP + 42 hours.

Compartment 17, MANURE --

Each day one-half of the pathogen population in Compartment 14, ANIMAL CONSUMPTION, is transferred to MANURE by TA1417. The inactivation of pathogens in MANURE is a function of both the ambient temperature of the pathway (set in the variable TEMP) and the moisture content of the manure. Each day's manure dries separately, as shown below in significant calculations.

Depending upon which type of cow is eating the sludge-fertilized crop, a fraction of the deposited MANURE will contact HIDE or UDDER. When the beef cow option is selected (COW = -1.), TA1718 transfers a fraction of the total pathogen population in MANURE (as specified by MANHID) to Compartment 18, HIDE, at the time of deposition. When the dairy cow option is operating (COW = +1.), TA1716 transfers a fraction of the pathogens to Compartment 16, UDDER. These transfers allow indirectly for the contamination of MEAT and MILK.

9-1/8"

Significant calculations - Drying of manure is based upon an 8-centimeter thick layer of 20 percent solids manure evaporating at 0.7 times the clear water evaporation rate for the Albuquerque, New Mexico area.

Percent solids (PRSOL) = 100 - (-5.33T + 80.), where T = days after first deposit of manure.

Time of first transfer into compartment - TCONSP + 40 hours.

Time of last transfer out of compartment - End of pathway.

Process function - RH017
Activated: TCONSP + 40 hours.
Duration: Until the pathway ends.
Rates: Salmonella: -0.46*N(17)/hour, for PRSOL $\geq$ 80. (8)
-3.45*N(17)/hour, for PRSOL < 80 and TEMP $\geq$ 45. (8, 93)
-0.048*N(17)/hour, for PRSOL < 80 and TEMP < 45. (8)
Ascaris: -0.251*N(17)/hour, for PRSOL $\geq$ 95. (22, 40, 74)
-1.535*N(17)/hour, for PRSOL < 95 and TEMP > 40. (7, 78)
0.0*N(17)/hour, for PRSOL < 95 and TEMP < 40.

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Poliovirus: $-0.384*N(17)$/hour, for TEMP $\geq$ 45. (88, 97)
$-0.0192*N(17)$/hour, for TEMP < 45 and PRSOL > 65. (87)
$-0.0104*N(17)$/hour, for TEMP < 45 and PRSOL $\leq$ 65. (44, 87)

Transfers into compartment -
TA1417 = N(14)/2. Transfer occurs at 24-hour intervals from TCONSP + 40 hours.

Transfers out of compartment -
TA1716 = MANUDR*N(17), Transfer occurs at 24-hour intervals from TCONSP + 41 hours.
TA1718 = MANHID*N(17), Transfer occurs at 24-hour intervals from TCONSP + 41 hours.

Compartment 18, HIDE --

This compartment represents the HIDE of the cows being fed the sludge-fertilized crop. Each day pathogens are transferred from Compartment 17, MANURE, to HIDE by TA1718. The user may specify the fraction of transfer by supplying a value for MANHID. If the beef cow option is selected (COW = -1.), a fraction of the pathogens on the HIDE will be transferred to MEAT at the time of slaughter on the day specified in TSLOTR. This fraction is specified by the variable FRSLOT. Pathogens transferred into this compartment are unaffected by process functions for 24 hours, at which time the population is reduced to zero.

Time of first transfer into compartment - TCONSP + 41 hours.

Time of last transfer out of compartment - TSLOTR.

Process function - RH018
Activated: TCONSP + 66 hours and then every 24 hours.
Duration: 1 hour for each 24-hour cycle.
Rates: Salmonella: -N(18)/hour.
Ascaris: -N(18)/hour.
Poliovirus: -N(18)/hour.

Transfers into compartment -
TA1718 = MANHID*N(17), Transfer occurs at 24-hour intervals from 41 hours.

Transfers out of compartment -
TA1815 = FRSLOT*N(18), Transfer occurs at TSLOTR.

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Job B

PATHWAY 7 - SLUDGE APPLICATION PATHWAY - ANIMAL FEED SUPPLEMENT

General Description

This pathway describes the fate of sewage sludge pathogens when a feed supplement produced from municipal sewage sludge is fed to cattle. Figure 7 shows the process compartments and transfers which define this application regime. The differential equations which describe this pathway are presented in Table 7a. Each process and transfer function is defined in the following section. Table 7b lists the definitions of and default values for the input variables used to define environmental factors which affect process and transfer functions. The model user may supply a value for any input variable and, thus, set the program to model a specific situation of concern. Table 7b also lists output variables generated by the computer program. These variables are not available to the user as input but are often used in pathway descriptions to define time increments and pathogen levels. The general considerations and assumptions discussed below were made to facilitate model development.

a. The pathway is designed to simulate a feedlot operation in which 100 animals, each weighing an average of 270 kilograms, are fed three percent of their weight each day in sewage sludge supplemented feed (dry weight). The feed is assumed to be 10 percent water by weight and to be similar to the feed produced by Pathway 2, Sludge Treatment Pathway - Animal Feed Supplement.

b. If the default values incorporated into the model are used, the pathway will run for 30 days. A longer period can be modeled by using the final pathogen counts in each compartment as the initial conditions of each compartment in a subsequent run. This is done by specifying each compartment number and the desired pathogen population for each compartment in the POPL variable of the $ARGS name list. The mechanism for setting initial pathogen populations is described in the user's manual for the program (Appendix A). If the beef cow option is chosen (COW = -1.) the pathway will terminate on the day of slaughter specified in the variable TSLOTR.

c. The ambient temperature of the environment is specified for each run of the model by the variable TEMP and remains constant throughout. The default ambient temperature is 20°C.

d. The amount of feed consumed each day (FDCONS) and the concentration of pathogens in that feed (ASCRS) are user-specifiable variables. The default values are based on using raw sludge from a municipal treatment system (1, 4, 28, 32, 77) in a 20 percent sludge supplemented feed. The value of the output variable NPFS in position 31 of Pathway 2's P-array is equal to the number of pathogens per kilogram of feed at the end of processing in Pathway 2. The user may run Pathway 2 for one of the three pathogens and then use the output value of NPFS as the value for ASCRS in this pathway. In this way Pathways 2 and 7 may be

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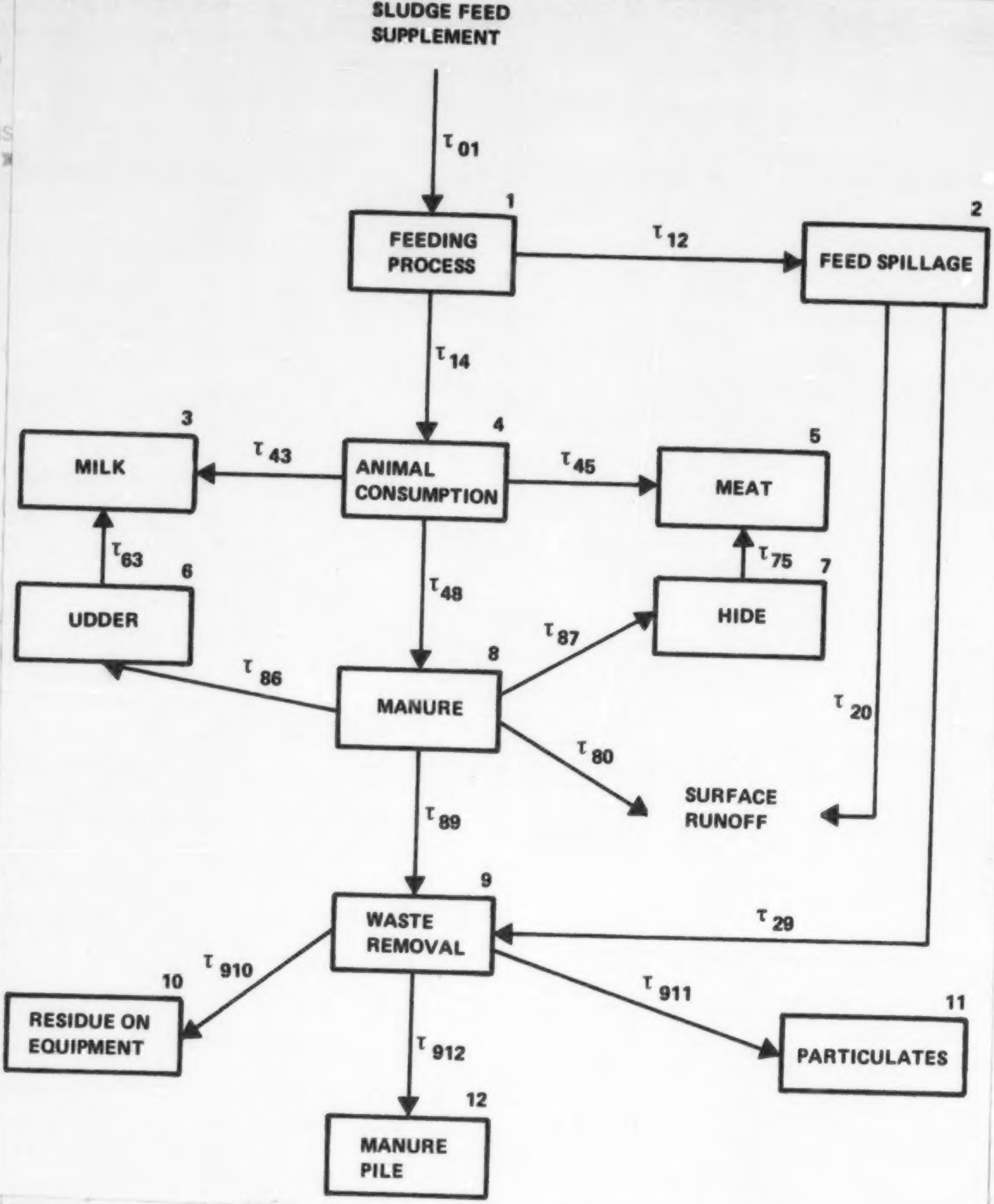
SLUDGE FEED SUPPLEMENT
τ 01
1
FEEDING PROCESS
τ 12
2
FEED SPILLAGE
τ 14
3
MILK
τ 43
4
ANIMAL CONSUMPTION
τ 45
5
MEAT
τ 63
6
UDDER
τ 48
τ 75
7
HIDE
τ 87
8
τ 86
MANURE
τ 20
τ 80
SURFACE RUNOFF
τ 89
9
WASTE REMOVAL
τ 29
τ 910
10
RESIDUE ON EQUIPMENT
τ 911
11
PARTICULATES
τ 912
12
MANURE PILE

Figure 7. Sludge Application Pathway - Animal Feed Supplement

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TABLE 7a. DIFFERENTIAL EQUATIONS FOR PATHWAY 7
SLUDGE APPLICATION PATHWAY - ANIMAL FEED SUPPLEMENT

$$\dot{N}_1 = \tau_{01} - \tau_{12} - \tau_{14} + \rho_1$$

$$\dot{N}_2 = \tau_{12} - \tau_{20} - \tau_{29} + \rho_2$$

$$\dot{N}_3 = \tau_{43} + \tau_{63} + \rho_3$$

$$\dot{N}_4 = \tau_{14} - \tau_{43} - \tau_{45} - \tau_{48} + \rho_4$$

$$\dot{N}_5 = \tau_{45} + \tau_{75} + \rho_5$$

$$\dot{N}_6 = \tau_{86} - \tau_{63} + \rho_6$$

$$\dot{N}_7 = \tau_{87} - \tau_{75} + \rho_7$$

$$\dot{N}_8 = \tau_{48} - \tau_{86} - \tau_{87} - \tau_{80} - \tau_{89} + \rho_8$$

$$\dot{N}_9 = \tau_{89} + \tau_{29} - \tau_{910} - \tau_{912} - \tau_{911} + \rho_9$$

$$\dot{N}_{10} = \tau_{910} + \rho_{10}$$

$$\dot{N}_{11} = \tau_{911} + \rho_{11}$$

$$\dot{N}_{12} = \tau_{912} + \rho_{12}$$

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TABLE 7b. VARIABLES FOR PATHWAY 7

SLUDGE APPLICATION PATHWAY - ANIMAL FEED SUPPLEMENT

POSITION	DEFAULT VALUE	VARIABLE	DEFINITION
		INPUT VARIABLES	
1	1.0E+6 1.0E+3 1.0E+7	ASCRS	Number of pathogens per kilogram of feed supplement.
2	1.05E+3	FDCONS	Kilograms of feed consumed per day.
3	ASCRS*FDCONS	ASCIN	Total number of pathogens entering pathway each day. If present, overrides the first two variables.
4	50.	WTSPIL	Dry weight in kilograms of feed spilled during feeding.
5	-2.	TRAIN	Time in hours of arbitrary rain. (If -2., there is no rain.)
6	0.01	FRRAIN	Fraction of transfer from Feed Spillage to Surface Runoff during rain.
7	20.	TEMP	Ambient temperature throughout pathway in degrees Celsius.
8	0.0	CONMLK	Fraction of transfer from Animal Consumption directly to Milk.
9	0.0	CONMET	Fraction of transfer from Animal Consumption directly to Meat.
10	-1.	COW	Animal type: +1.0 = dairy herd. -1.0 = beef herd.
11	0.005	FRHIDE	Fraction of transfer from Manure to Hide.
12	0.001	FRUDDR	Franction of transfer from Manure to Hide.

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TABLE 7b. (continued)

POSITION	DEFAULT VALUE	VARIABLE	DEFINITION
13	0.01	FRAIN2	Fraction of transfer from Manure to Surface Runoff during rain.
14	0.0	UDRMLK	Fraction of transfer from Udder to Milk.
15	10.	WTRS10	Dry weight in kilograms of residue left on waste removal equipment.
16	5.	WTPR11	Dry weight in kilograms of particulates generated by waste removal equipment.
17	-2.	TSLOTR	Time of slaughter in days. (If -2. there is no slaughter.)
18	0.10	FRSLOT	Fraction of transfer from Hide to Meat at slaughter.
		OUTPUT VARIABLES	
19	(output)	TAU14	Threshold dose levels in State 4.
20	(output)	WTMANR	Weight of manure removed from pen.
21	(output)	SOLIDS	Percent solids of manure.

NOTES: The number of pathogens per day entering the pathway will default to FDCONS*ASCRS if no value is specified for ASCIN. If a value is specified for ASCIN, it will override the FDCONS*ASCRS value.

Whenever three default values are specified for any variable in the list above, the order is salmonellae, ascaris, poliovirus pathogen types. The appropriate default value will be selected to agree with the pathogen type being considered in a particular run.

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TABLE 7b. (concluded)

NOTES (concluded):

All units of measure are in kilograms, degrees Celsius, or hours unless otherwise stated.

Variables labeled "output" are for internal computations and are not available to the user as input.

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linked and a selected pathogen followed through the preparation and use of a sludge-supplemented feed.

e. The area of the feedlot, which is used in determining particulates generation and manure drying, is 400 square meters or 4 square meters per animal (46). Particulates generated throughout the pathway are a maximum of 15 mg/m³ over the area of the feedlot and to a height of 10 meters (82).

f. When the cows are fed (once each day) a portion of the feed will spill and directly contaminate the feedlot. Spillage is defined by the variable WTSPIL. The default value for this variable assumes that 5 percent of the feed will spill.

g. Each cow will add 10 kilograms of manure at 80 percent moisture (58, 60) to the feedlot each day. This addition will occur for all cows at one time to simplify the bookkeeping on manure process functions. Manure is assumed to dry at a rate which is based on sludge evaporation (10) with the manure spread 8 centimeters deep over the area of the pen each day. Every 7 days the accumulated manure, which is at seven different stages of dryness, is removed to a storage pile. Particulates generated during removal and the residue left on equipment are handled as in previous pathways.

h. The user must decide before each pathway run if the cattle being fed the crop are a diary herd and milked or are a beef herd and may be slaughtered for meat. If the diary option (COW = +1.) is selected, cows are milked twice a day at 12-hour intervals. Each cow will deliver 15 liters of milk at each milking (65). The milk is stored at 4°C regardless of the ambient temperature selected for a model run. The total growth of salmonella in milk is limited to 1×10^{12} per liter. If the beef herd option is selected (this is the default condition), a fraction of the manure which contacts hide will be transferred to meat during slaughter (91) if a value is specified for the variable TSLOTR. Each cow yields 270 kilograms of meat (53).

i. Salmonella infections in cattle can be systemic (13). Transfers of pathogens directly from the cow to milk and meat are included in the pathway (TAU43 and TAU45, respectively). Because infections of adult cattle are usually nonsymptomatic and localized in the mesenteric lymph nodes (5), default values for the fraction of transfer directly to milk and meat (variables CONMLK and CONMET, respectively) are zero for all pathogens. Infections in cattle are assumed to occur whenever the total consumption of salmonella exceeds 1×10^9 cells per day. In the event of infection, the number excreted per cow per day in manure is increased to 1×10^{12}. Cows cannot be infected by poliovirus or ascaris ova (ascaris in this model always refers to *Ascaris lumbricoides*). Both are assumed to be unaffected by herbivore digestion and to be excreted in the same numbers as ingested.

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Milk and meat can be contaminated by contact with manure. All three pathogens can be transferred by this route.

j. An optional rain is included in the pathway. If requested, the rain results in surface runoff which removes a fraction of the manure and feed-spillage-associated pathogens specified by the variables FRRAIN and FRAIN2. This removal may be user determined to agree with available rainfall-runoff models for feedlots.

Compartment 1, FEEDING PROCESS --
The feedlot is assumed to be occupied by 100 cows when the pathway begins. These cows are fed an amount of sewage-sludge-supplemented feed specified by the variable FDCONS each day. The user may determine the concentration of pathogens in the feed by specifying a value for ASCRS. The time of the first feeding starts the pathway.

Pathogens are transferred from this compartment to Compartment 4, ANIMAL CONSUMPTION, by TAU14 over a 4-hour period. Pathogens are also transferred to Compartment 2, FEED SPILLAGE, by TAU12 over the same time period. TAU14 simulates the ingestion of feed by the cows, while TAU12 simulates the spillage of feed during the time when it is offered to the cows and later by the cows themselves. The user may specify the weight of feed spilled by giving a value to WTSPIL.

Time of first transfer into compartment - Start of pathway.

Time of last transfer out of compartment - 696 hours when the pathway runs 30 days.

Process function - RHO1
Activated: Start of pathway.
Duration: Until the end of the pathway.
Rates: Salmonella: 0.0*N(1)/hour.
Ascaris: 0.0*N(1)/hour.
Poliovirus: 0.0*N(1)/hour.

Transfers into compartment -
TAU01 = ASCIN, Transfer occurs at the start of the pathway and then daily.

Transfers out of compartment -
TAU12 = (WTSPIL/FDCONS)*N(1), Transfer occurs at 24-hour intervals from 2 hours into the pathway.
TAU14 = N(1) - TAU12, Transfer occurs at 24-hour intervals from 2 hours into the pathway.

Compartment 2, FEED SPILLAGE --
During the FEEDING PROCESS a portion of the sewage-sludge-supplemented feed is assumed to spill on the ground. This transfer is simulated by TAU12. The weight of spillage may be specified by supplying a value for WTSPIL. Pathogens are removed from this compartment in two ways. If

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the user chooses rain by specifying a positive value for the variable TRAIN, a portion of the spilled feed, specified by the variable FRRAIN, will be transferred to SURFACE RUNOFF by TAU20. Every 7 days when the feedlot is cleared of manure accumulations it is also cleared of accumulated spilled feed. This transfer is accomplished by TAU29.

Time of first transfer into compartment - 2 hours into pathway.

Time of last transfer out of compartment - End of pathway.

Process function - RHO2
Activated: 6 hours into pathway.
Duration: Until the end of the pathway.
Rates: Salmonella: -0.46*N(2)/hour, TEMP > 40. (8)
0.0*N(2)/hour, for TEMP < 40.
Ascaris: -1.53*N(2)/hour, for TEMP > 40. (7,78)
0.0*N(2)/hour, for TEMP < 40.
Poliovirus: -0.019*N(2)/hour, for TEMP > 40. (87)
0.0*N(2)/hour, for TEMP ≤ 40.

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Transfers into compartment -
TAU12 = (WTSPIL/FDCONS)*N(1), Transfer occurs at 24-hour intervals from 2 hours.

Transfers out of compartment -
TAU20 = FRRAIN*N(2), Transfer occurs at TRAIN.
TAU29 = N(2) - TAU20, Transfer occurs at 7-day intervals from 168 hours.

Compartment 3, MILK --

The cows are milked twice each day when the dairy cow option is chosen (COW = +1.). The MILK is kept at 4°C for 11 hours but is assumed to be removed from the pathway before the next milking. Pathogens can be transferred to MILK directly from Compartment 4, ANIMAL CONSUMPTION, by TAU43. This transfer will simulate the possible effects of a systemic salmonella infection. The user must supply a value for CONMLK, the variable which specifies the fraction of Compartment 4 pathogens transferred. The default value for this variable is zero. Neither poliovirus nor ascaris are known to infect cattle and would not pass from the gut.

Pathogens are more readily transferred into milk by dirty utensils and careless handling. In the model these are combined as a transfer from manure-contaminated UDDER, Compartment 6. Transfer TAU63 occurs at each milking. All three pathogens can enter MILK by this route. The default value for UDRMLK is an estimate. There are no transfers out of this compartment but the pathogen population is used in milk-exposure risk calculations.

Time of first transfer into compartment - 40 hours into pathway.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathway terminates.

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Process function - RHO3
Activated: 52 hours into the pathway.
Duration: 11 hours after each milking.
Rates: Salmonella: $0.076*N(3)$/hour to a limit of 1×10^{12} salmonella per milliliter of milk. Salmonella is allowed to grow at a generation time of 6 hours at 4°C.
Ascaris: $0.0*N(3)$/hour.
Poliovirus: $0.0*N(3)$/hour. Poliovirus and ascaris remain at the level transferred in.

Transfers into compartment -
TAU43 = CONMLK*N(4), Transfer occurs at 12-hour intervals from 40 hours.
TAU63 = UDRMLK*N(6), Transfer occurs at 12-hour intervals from 52 hours into pathway.

Transfers out of compartment - None.

Compartment 4, ANIMAL CONSUMPTION --

This compartment represents 100 feedlot-confined cows as they consume the sewage-sludge-supplemented feed and digest it. Pathogens are transferred into this compartment from Compartment 1, FEEDING PROCESS, by TAU14. Although eating is a rather continuous process for cows, the transfer into this compartment is made once a day as a discrete event starting 2 hours into the pathway.

In the absence of data, it was assumed that herbivore digestive processes would not alter ingested pathogen populations. The possibility of infection by salmonella was taken into account. If the total daily transfer of pathogens into the compartment exceeds 1×10^9 salmonella per cow, infection is simulated by increasing the population in the compartment by three orders of magnitude and excreting this larger number in the manure. Transfers TAU43 and TAU45, from ANIMAL CONSUMPTION to MILK and MEAT, may also be used to simulate the effects of salmonella infection. While the default values for both CONMET and CONMLK (the variables which specify the fraction of direct transfer of salmonella from ANIMAL CONSUMPTION to MEAT and MILK, respectively) are zero, the user may input values to indicate contamination of foodstuffs as a result of systemic infection.

Materials which are consumed by the cows have a 2-day residence time before being excreted to MANURE by TAU48. One-half of the pathogen population of Compartment 4 is transferred to Compartment 8 each day as a discrete event.

Time of first transfer into compartment - 2 hours into pathway.

Time of last transfer out of compartment - End of pathway.

Process function - RHO4
Activated: 2 hours into pathway.
Duration: Until the pathway ends.

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Rates: Salmonella: If TAU14 $\geq 1 \times 10^{11}$, there is an immediate increase to 5×10^{14}. If TAU14 < 1×10^{11}, there is no change in the population in this compartment, 0.0*N(4)/hour.
Ascaris: 0.0*N(4)/hour.
Poliovirus: 0.0*N(4)/hour.

Transfers into compartment -
TAU14 = N(1) - TAU12, Transfer occurs at 24-hour intervals from 2 hours.

Transfers out of compartment -
TAU43 = CONMLK*N(4), Transfer occurs at 12-hour intervals from 40 hours into the pathway.
TAU45 = CONMET*N(4), Transfer occurs at 24-hour intervals from 40 hours into the pathway.
TAU48 = N(4)/2., Transfer occurs at 24-hour intervals from 48 hours into the pathway.

6-1/2"

Compartment 5, MEAT --

If the beef cow option is chosen (this is the default condition), the cows on the feedlot can be slaughtered at TSLOTR. This variable must be set by the user to be a time less than 30 days (the time the pathway ends under default values). Slaughter will occur when pathogen levels in the cows are highest on the day assigned to TSLOTR. At slaughter, the cows become 27,000 kilograms of MEAT (100 cows x 270 kilograms per cow). Pathogens can be transferred to MEAT by two routes. Salmonella can infect a cow. TAU45 simulates the direct transfer of pathogens from ANIMAL CONSUMPTION, Compartment 4, to MEAT. The default value for CONMET is zero since no data could be found quantifying the contamination of meat from a systemic salmonella infection and neither ascaris nor poliovirus should transfer from the gut of the cow. The user can assign a value to CONMET if contamination of MEAT by a systemic infection is desired. This transfer would occur daily but only for salmonella pathogen type.

When cattle are butchered, the MEAT is often contaminated by enteric bacteria. The model shows this transfer as being between the manure-contaminated HIDE and the MEAT. TAU75 will occur at TSLOTR. Default values for FRSLOT, the fraction of HIDE pathogens transferred to MEAT, are available for all three pathogen types. These are, of course, estimates. MEAT is assumed to be kept at 4°C following slaughter. There are no transfers out of this compartment but the pathogen population is used in meat-exposure risk calculations.

Time of first transfer into compartment - 40 hours into the pathway.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathway terminates.

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Process function - RHO5
Activated: 40 hours into pathway.
Duration: Until the pathway ends.
Rates: Salmonella: 0.076*N(5)/hour to an upper limit of 1 x 10^8 salmonella per kilogram of meat. Salmonella is allowed to grow at a generation time of 6 hours at 4°C.
Ascaris: 0.0*N(5)/hour.
Poliovirus: 0.0*N(5)/hour. Poliovirus and ascaris remain at the level transferred at slaughter.

Transfers into compartment -
TAU45 = CONMET*N(4), Transfer occurs 40 hours into the pathway and then at 24-hour intervals.
TAU75 = FRSLOT*N(7), Transfer occurs at TSLOTR.

Transfers out of compartment - None.

Compartment 6, UDDER --

This compartment provides for an indirect transfer of MANURE-associated pathogens to MILK. Pathogens are transferred from Compartment 8, MANURE, to UDDER by TAU86 once each day. The number transferred is controlled by the variable FRUDDR. If the dairy cow option is selected (COW = +1.), a fraction of the pathogens on the udder will be transferred to MILK during each milking. This fraction is specified by the variable UDRMLK.

Time of first transfer into compartment - 49 hours into pathway.

Time of last transfer out of compartment - 8 hours before the pathway ends.

Process function - RHO6
Activated: 49 hours into pathway.
Duration: Until pathway ends.
Rates: Salmonella: 0.0*N(6)/hour.
Ascaris: 0.0*N(6)/hour.
Poliovirus: 0.0*N(6)/hour.

Transfers into compartment -
TAU86 = FRUDDR*N(8), Transfer occurs at 24-hour intervals from 49 hours into pathway.

Transfers out of compartment -
TAU63 = UDRMLK*N(6), Transfer occurs at 12-hour intervals from 52 hours.

Compartment 7, HIDE --

This compartment represents the HIDE of the feeding cattle. Each day pathogens are transferred from Compartment 8, MANURE, to HIDE by TAU87. The user may specify the fraction of transfer by supplying a value for

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FRHIDE. If the beef cow option is selected (COW = -1.), a fraction of the pathogens on the HIDE will be transferred to MEAT at the time of slaughter on the day specified in TSLOTR. This fraction is specified by variable FRSLOT.

Time of first transfer into compartment - 49 hours into pathway.

Time of last transfer out of compartment - TSLOTR.

Process function - RH07
  Activated: 50 hours into pathway.
  Duration: 1 hour.
  Rates: Salmonella: N(7) = 0.0, after 1 hour.
    Ascaris: N(7) = 0.0, after 1 hour.
    Poliovirus: N(7) = 0.0, after 1 hour.

Transfers into compartment -
  TAU87 = FRHIDE*N(12), Transfer occurs at 24-hour intervals from 49 hours.

6-1/2"

Transfers out of compartment -
  TAU75 = FRSLOT*N(7), Transfer occurs on day TSLOTR at 50 hours + a multiple of 24 hours.

Compartment 8, MANURE --

Each day one-half of the pathogen population in Compartment 4, ANIMAL CONSUMPTION, is transferred to MANURE by TAU48. The inactivation of pathogens in MANURE is a function of both the ambient temperature of the pathway (set in the variable TEMP) and the moisture content of the manure. Each day's manure dries separately as shown below in significant calculations.

Depending upon which type of cow is on the feedlot, a fraction of the deposited MANURE will contact HIDE or UDDER. When the beef cow option is selected (COW = -1.), TAU87 transfers a fraction of the total pathogen population in MANURE (as specified by FRHIDE) to Compartment 7, HIDE, at the time of deposition. When the dairy cow option is operating (COW = +1.), TAU86 transfers a fraction of the pathogens to Compartment 6, UDDER. These transfers allow indirectly for the contamination of MEAT and MILK.

If there is a rain (TRAIN is set to a positive number), a fraction of the pathogens associated with the MANURE (FRAIN2) will be washed from the feedlot by TAU80. These pathogens are transferred to SURFACE RUNOFF, which is not defined as a compartment in this model. (The scope of the model is not large enough to follow pathogens beyond the area of the feedlot, SURFACE RUNOFF by definition leaves the area.)

Once a week the accumulated manure in the feedlot is removed, an operation simulated in Compartment 9, WASTE REMOVAL. TAU89 transfers the pathogen population from MANURE to WASTE REMOVAL at weekly intervals.

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Significant calculations - The solid content of MANURE (variable SOLIDS) changes with time. Each new deposit of manure is assumed to be only 20 percent solids. This portion dries at a rate based on an 8-centimeter thick layer evaporating at 0.7 times the clear water evaporation rate for the Albuquerque, New Mexico area.

Percent solids (SOLIDS) = 100. - (-5.33*FLOAT(I) + 80). Each days's deposit of manure is tracked separately. On day 7 the first deposit of manure has a solids content of

$$100. - (-5.33*7. + 80) = 57.31$$

The second day's deposit would have a solids content of

$$100. - (5.33*6. + 80) = 51.98$$

giving an average of 54.64 for a homogeneous mixture.

Time of first transfer into compartment - 48 hours into pathway.

6-1/2"

Time of last transfer out of compartment - End of pathway.

Process function - RH08
Activated: 48 hours into pathway.
Duration: Until the pathway ends.
Rates: Salmonella: -0.048*N(8)/hour, for SOLIDS < 80 and TEMP < 20. (8)
0.13*N(8)/hour, for SOLIDS < 80 and 20 < TEMP < 45. (8)
-3.45*N(8)/hour, for SOLIDS < 80 and TEMP > 45. (8, 93)
-0.46*N(8)/hour, for SOLIDS > 80. (8)
Ascaris: -1.53*N(8)/hour, for SOLIDS < 95 and TEMP > 40. (7, 78)
-0.25*N(8)/hour, for SOLIDS > 95. (22, 40, 74)
0.0*N(8)/hour, for SOLIDS < 95 and TEMP ≤ 40. (7, 9, 40)
Poliovirus: -0.01*N(8)/hour, for SOLIDS < 65 and TEMP < 45. (44, 87)
-0.019*N(8)/hour, for SOLIDS ≥ 65 and TEMP < 45. (87)
-0.38*N(8)/hour, for TEMP ≥ 45. (88, 97)

Transfers into compartment -
TAU48 = N(4)/2., Transfer occurs at 24-hour intervals from 48 hours.

Transfers out of compartment -
TAU80 = FRAIN2*N(8), Transfer occurs at TRAIN.
TAU86 = FRUDDR*N(8), Transfer occurs at 24-hour intervals from 49 hours when COW = +1.

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TAU87 = FRHIDE*N(8), Transfer occurs at 24-hour intervals from 49 hours when COW = -1.
TAU89 = N(8) - TAU87 - TAU80 - TAU86, Transfer occurs at 7-day intervals from 168 hours.

Compartment 9, WASTE REMOVAL --

Each day each cow contributes 10 kilograms of manure to the feedlot. Since there are 100 cows on the lot, at the end of a week 7000 kilograms of manure have accumulated in the feedlot. At this time the manure is scraped up along with any spilled feed and removed to the MANURE PILE. This compartment represents that removal. It lasts 1 hour; no process functions have been defined for such a short period.

Pathogens enter this compartment from Compartment 8, MANURE, by TAU89 and from Compartment 2, FEED SPILLAGE, by TAU29. All the pathogens present in both compartments transfer into WASTE REMOVAL once each week.

Pathogens are transferred from WASTE REMOVAL to Compartment 10, RESIDUE ON EQUIPMENT, by TAU910; to Compartment 11, PARTICULATES, by TAU911; and to Compartment 12, MANURE PILE, by TAU912. A portion of the manure is assumed to remain on removal equipment. The user may specify the weight involved by assigning a value to the variable WTRS10. Similarly, the scraping operation will generate dust and the user may specify the weight of manure transferred to Compartment 11 by assigning a value to the variable WTPR11. All manure and spilled-feed associated pathogens not transferred to RESIDUE or PARTICULATES are transferred to the MANURE PILE. These transfers all take place once each week.

Time of first transfer into compartment - 168 hours into pathway.

Time of last transfer out of compartment - End of pathway.

Process function - RHO9
Activated: 168 hours into pathway and then at 7-day intervals.
Duration: 1 hour.
Rates: Salmonella: 0.0*N(9)/hour.
Ascaris: 0.0*N(9)/hour.
Poliovirus: 0.0*N(9)/hour.

Transfers into compartment -
TAU29 = N(2) - TAU20, Transfer occurs at 7-day intervals from 168 hours.
TAU89 = N(8) - TAU87 - TAU80 - TAU86, Transfer occurs at 7-day intervals from 168 hours.

Transfers out of compartment -
TAU910 = (WTRS10/WTMANR)*N(9), Transfer occurs at 7-day intervals from 169 hours.
TAU911 = (WTPR11/WTMANR)*N(9), Transfer occurs at 7-day intervals from 169 hours.
TAU912 = N(9) - TAU910 - TAU911, Transfer occurs at 7-day intervals from 169 hours.

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Compartment 10, RESIDUE ON EQUIPMENT --

Some of the manure scraped from the feedlot in Compartment 9 will remain on the removal equipment. The amount is specified by the variable WTRS10. The pathogens associated with residue die off rapidly due to desiccation. Process functions are activated 1 hour after the removal process ends.

Time of first transfer into compartment - 169 hours into the pathway.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RH010

Activated:	170 hours into the pathway.		
Duration:	Until all pathogens are depleted or the pathway ends.		
Rates:	Salmonella:	-0.46*N(10)/hour.	(8)
	Ascaris:	-0.25*N(10)/hour.	(22, 40, 74)
	Poliovirus:	-0.38*N(10)/hour.	(88, 97)

6-1/2"

Transfers into compartment -
TAU910 = (WTRS10/WTMANR)*N(9), Transfer occurs at 7-day intervals from 169 hours.

9-1/8"

Transfers out of compartment - None.

Compartment 11, PARTICULATES --

The removal of manure and spilled feed will generate dust to a level of 15 mg/m^3 in a volume extending 10 meters above the 400-square-meter feedlot when default values are used. The user may specify a value for WTPR11 if a different concentration is desired. The pathogens in airborne particulates are rapidly desiccated.

Time of first transfer into compartment - 169 hours into the pathway.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RH011

Activated:	170 hours into the pathway.		
Duration:	Until all pathogens are depleted or the pathway ends.		
Rates:	Salmonella:	-0.46*N(11)/hour.	(8)
	Ascaris:	-0.25*N(11)/hour.	(22, 40, 74)
	Poliovirus:	-0.38*N(11)/hour.	(88, 97)

Transfers into compartment -
TAU11 = (WTPR11/WTMANR)*N(9), Transfer occurs at 7-day intervals from 169 hours.

Transfers out of compartment - None.

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Compartment 12, MANURE PILE --

This compartment represent a storage area for feedlot wastes. It is a final sink for the pathogens associated with waste material. Although manure may be put to further use, these applications and pathogen transfers are beyond the scope of this pathway.

Time of first transfer into compartment - 170 hours into the pathway.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RH012
Activated: 170 hours into the pathway.
Duration: Until all pathogens are depleted or the pathway ends.
Rates: Salmonella: -0.024*N(12)/hour. (8) This is one-half the rate of inactivation for salmonella in drying sludge at greater than 80 percent solids.
Ascaris: -0.0000714*N(12)/hour. (75)
Poliovirus: -0.01*N(12)/hour. (44, 87)

Transfers into compartment -
TAU912 = N(9) - TAU910 - TAU911, Transfer occurs at 7-day intervals from 169 hours.

Transfers out of compartment - None.

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PATHWAY 8 - SLUDGE APPLICATION PATHWAY - RESIDENTIAL GARDEN SOIL AMENDMENT

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General Considerations

This pathway describes the fate of sewage sludge pathogens after application of composted sludge to a 0.015-hectare home vegetable garden. Figure 8 shows the process compartments and transfers which define this application regime. The differential equations which describe this pathway are presented in Table 8a. Each process function and transfer function is defined in the following section. Table 8b lists the definitions of and default values for the input variables used to define environmental factors which affect process and transfer functions. The model user may supply a value for any input variable and, thus, set the program to model a specific situation of concern. The general considerations and assumptions discussed below were made to facilitate model development.

a. The duration of the pathway is determined by the user. The pathway terminates after crops are harvested, and the user may specify growth periods appropriate to ripen a chosen crop. The default pathway duration of 1640 hours is an average value when the three vegetables used as examples are grown under adequate irrigation in the sunny Southwest (18, 67). Varying pathway duration by changing the value of THARV will simulate other climates.

b. The ambient temperature of the environment is specified for each run of the model by the variable TEMP and remains constant throughout. The default ambient temperature is 20°C.

c. The amount of compost applied to the garden (APRATE) and the concentration of pathogens in that compost (ASCRS) are user-specifiable variables. The model allows one application of composted sludge which is turned into the soil before crops are seeded. There are no additional applications of sludge prior to harvest. Default values are based on adding a moderate amount of compost (48), approximately 60,000 dry kilograms per hectare (25 tons per acre), to the garden. The default values for the number of pathogens present in the compost reflect a conservative "worst case" and are set equal to the concentration of each pathogen in raw sludge from a municipal treatment system (1, 4, 28, 32, 77). The value of output variable NPKC, position 67 of Pathway 3's P-array, is equal to the number of pathogens per kilogram of compost at the end of a run of Pathway 3. The user may run Pathway 3 for one of the three pathogens and then use the output value of NPKC as the value for ASCRS, the variable in position 1 of Pathway 8's P-array. ASCRS determines the number of pathogens per kilogram of compost applied to the garden. In this way Pathways 3 and 8 may be linked and a selected pathogen followed through treatment and application of sludge.

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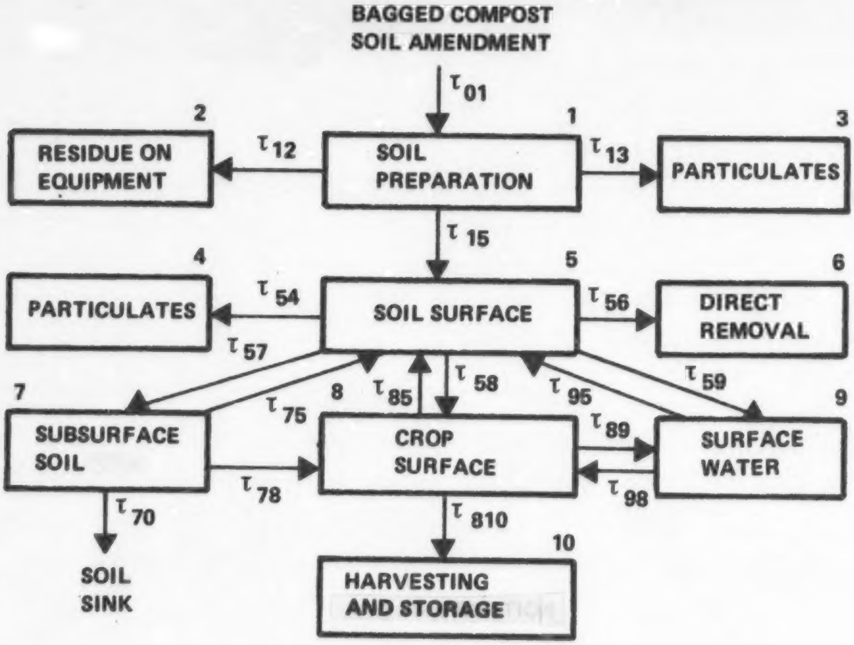
BAGGED COMPOST
SOIL AMENDMENT
τ_{01}
1
SOIL PREPARATION
2
RESIDUE ON EQUIPMENT
τ_{12}
τ_{13}
3
PARTICULATES
τ_{15}
4
PARTICULATES
τ_{54}
5
SOIL SURFACE
τ_{56}
6
DIRECT REMOVAL
τ_{57}
τ_{85}
τ_{58}
τ_{95}
τ_{59}
7
SUBSURFACE SOIL
τ_{75}
8
CROP SURFACE
τ_{89}
9
SURFACE WATER
τ_{78}
τ_{98}
τ_{70}
SOIL SINK
τ_{810}
10
HARVESTING AND STORAGE

Figure 8. Sludge Application Pathway - Residential Garden Soil Amendment

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TABLE 8a. DIFFERENTIAL EQUATIONS FOR PATHWAY 8
SLUDGE APPLICATION PATHWAY - RESIDENTIAL GARDEN SOIL AMENDMENT

$$\dot{N}_1 = \tau_{01} - \tau_{12} - \tau_{13} - \tau_{15} + \rho_1$$

$$\dot{N}_2 = \tau_{12} + \rho_2$$

$$\dot{N}_3 = \tau_{13} + \rho_3$$

$$\dot{N}_4 = \tau_{54} + \rho_4$$

$$\dot{N}_5 = \tau_{15} + \tau_{75} + \tau_{85} + \tau_{95} - \tau_{54} - \tau_{56} - \tau_{57} - \tau_{58} - \tau_{59} + \rho_5$$

$$\dot{N}_6 = \tau_{56} + \rho_6$$

$$\dot{N}_7 = \tau_{57} - \tau_{70} - \tau_{75} - \tau_{78} + \rho_7$$

$$\dot{N}_8 = \tau_{58} + \tau_{78} + \tau_{98} - \tau_{85} - \tau_{89} - \tau_{810} + \rho_8$$

$$\dot{N}_9 = \tau_{59} + \tau_{89} - \tau_{95} - \tau_{98} + \rho_9$$

$$\dot{N}_{10} = \tau_{810} + \rho_{10}$$

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TABLE 8b. VARIABLES FOR PATHWAY 8

SLUDGE APPLICATION PATHWAY - RESIDENTIAL GARDEN SOIL AMENDMENT

POSITION	DEFAULT VALUE	VARIABLES	DEFINITION
		INPUT VARIABLES	
1	1.95E+7 4.95E+2 6.52E+7	ASCRS	Number of pathogens per kilogram of applied compost.
2	8.818E+4	APRATE	Application rate of compost in kilograms per hectare.
3	0.015	GSIZE	Size of garden in hectares.
4	ASCRS*APRATE* GSIZE	ASCIN	Total number of pathogens entering pathway. If present, overrides first three variables.
5	0.5	WTRES2	Dry weight in kilograms of compost transferred to Residue in Compartment 2.
6	2.25E-2	WTPAR3	Dry weight in kilograms of particulates generated in Compartment 3.
7	20.	TEMP	Ambient temperature throughout the pathway in degrees Celsius
8	1.0E+9	UPLIM	Maximum population of salmonellae permitted in Compartment 5 per kilogram of compost applied.
9	2.25E-2	WTPAR4	Dry weight in kilograms of particulates generated in Compartment 4 during windstorm.
10	0.5	DIRMOV	Dry weight in kilograms of transfer form Soil Surface to Direct Removal.
11	0.05 0.01 0.05	TRNSUR	Fraction of transfer from Soil Surface to Surface Water.

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TABLE 8b. (continued)

POSITION	DEFAULT VALUE	VARIABLES	DEFINITION
12	0.0	CROP	Type of crop being grown: +1. = Above-ground 0. = On-ground -1. = Below-ground
13	4.33E-8	FCROP1	Fraction of transfer from Soil Surface to above-ground Crop Surface.
14	0.006	FCROP2	Fraction of transfer from Soil Surface to on-ground Crop Surface at harvest.
15	0.00096	FCROP3	Fraction of transfer from Soil Surface to below-ground Crop Surface at harvest.
16	0.001 0.0 0.83	TRSUB	Fraction of transfer from Soil Surface to Subsurface Soil.
17	2.	FILTR8	Infiltration rate of Surface Water in centimeters per hour.
18	3.	DEPTH	Depth of irrigation water in centimeters.
19	0.0001	FCROP4	Fraction of transfer from Surface Water to above-ground Crop Surface.
20	0.012	FCROP5	Fraction of transfer from Surface Water to on-ground Crop Surface.
21	0.0	FCROP6	Fraction of transfer from Surface Water to below-ground Crop Surface.
22	0.0	TRSUR	Fraction of transfer from Subsurface Soil to Soil Surface at cultivation. (If J 0., cultivation occurs. If = 0., no cultivation or transfer.)

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TABLE 8b. (concluded)

POSITION	DEFAULT VALUE	VARIABLES	DEFINITION
23	1.92E-4	FCROP7	Fraction of transfer from Subsurface Soil to below-ground Crop Surface.
24	0.1 0.01 0.1	SINK	Fraction of transfer from Subsurface Soil to Soil Sink.
25	1640.	THARV	Time of harvest in hours.
26	0.2	TCSSS	Transfer from above-ground Crop Surface to Soil Surface.
		OUTPUT VARIABLES	
27	(output)	FPCU	Final pathogen count per crop unit.

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NOTES: The number of pathogens per day entering the pathway will default to ASCRS*APRATE*GSIZE if no value is specified for ASCIN. If a value is specified for ASCIN, it will override the calculated value.

Whenever three default values are specified for any variable in the list above, the order is salmonellae, ascaris, poliovirus pathogen types. The appropriate default value will be selected to agree with the pathogen type being considered in a particular run.

All units of measure are in kilograms, degrees Celsius, or hours unless otherwise stated.

Variables labeled "output" are for internal computations and are not available to the user as input.

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d. The area of the garden is variable and is specified by GSIZE. The default value of 0.015 hectares reflects the size of an average suburban backyard. The area selected will determine crop yields.

e. The pathway is defined for three types of crops:
Above-ground -- vegetables which ripen on bushy plants above the ground and which do not directly contact either the soil surface or irrigation water during growth. Hybrid tomatoes were used as the example. They are spaced in rows 1.5 meters apart with plants on 0.5-meter centers within each row and will produce 2.2 kilograms of tomatoes per meter of row (34). Tomatoes were modeled as perfect spheres 10 centimeters in diameter and weighing 0.2 kilograms each (15).

On-ground -- vegetables which grow on spreading vines or runners and which lie directly on the ground during most of their growing period. These vegetables are in direct contact with the surface soil and may be covered by irrigation water if the depth of irrigation exceeds the size of the vegetables. Zucchini squash was used as the example. Spacing for the crop is 1 meter between rows and 0.5 meter between plants within the rows (15, 34). Each plant will produce two squash which were modeled as perfect cylinders 20 centimeters long by 5 centimeters in diameter and weighing 0.2 kilogram. One-half the area of each squash is assumed to rest directly on the soil surface.

Below-ground -- root and tuber vegetables which develop completely underground. Carrots were used as the example of below-ground crops. Rows of carrots are spaced 0.5 meter apart with 0.1 meter between thinned plants (15, 34). Carrots are assumed to be perfect cylinders 20 centimeters long by 2.5 centimeters in diameter and weighing 0.1 kilogram. Because of their length, one-half of each carrot extends into the subsurface soil.

The user must select one crop type for each run of the pathway.

f. At the time of application, compost is turned into the soil - an operation which creates two distinct soil layers. The upper 10 centimeters of soil is a homogeneous mixture of compost and soil. This zone is affected by changing temperatures and dries after each watering. The next 50 centimeters is the subsurface soil layer. This zone has a constant temperature and moisture level. Pathogens enter this zone with percolating water. Transfers of pathogens from both soil layers to crop surfaces are under some constraints which are discussed below.

g. Pathogens in the surface soil are transferred to above-ground crops once during the crop cycle, when a wind storm stirs up dust in a 10-meter high volume above the garden. A fraction of this dust, in proportion to the volume of tomatoes relative to the volume above the field, settles on tomatoes. As with

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particulates throughout all model pathways, the dust is assumed to be at a concentration of 15 mg/m³ (82). Pathogens in the dust on above-ground crop surfaces will die off at a constant rate until crop harvest, and a fraction will fall off the fruit and return to the soil surface. Pathogens from subsurface soil will not contact above-ground crops.

On-ground crops are in constant contact with surface soil and are considered to be at equilibrium with the soil, transferring as many pathogens to soil as are transferred from the soil, until harvest when a percentage of the total pathogen content of the surface soil layer is transferred to the crop. That percentage is based on a ratio of crop area in contact with the soil to the area of the garden. All crops are assumed to be nonexistent until day 50 and from then on to be full sized at harvest regardless of the harvest time selected. Pathogens in the subsurface soil do not contact on-ground crops.

Crops growing below ground are part of the soil until harvest when a fraction of both surface and subsurface soil pathogens are transferred to the crop. The ratio of the volume of the crop in each soil layer to the total volume of each layer determines the number of pathogens transferred.

h. Default values for soil factors describe a sandy loam soil. The water infiltration rate (26, 33) and water holding capacity of the soil (80) are functions of soil type and determine the duration of the soil surface water compartment. Values used in the transfer of pathogens from the surface to subsurface soil zones were based on the ability of sandy loam soils to filter and adsorb particles of different sizes carrying different charges. Variables are provided in the model for soil factors and the fractions of transfer between pathway compartments. The user may specify values for these variables which describe other soil types.

i. The garden is watered after compost application and every 3 days thereafter. The user may control the amount of water applied by specifying a value for the variable DEPTH. The default value is 3 centimeters. The water is assumed to be from a domestic outlet and to be of drinking water quality. It infiltrates the soil at a constant and uniform rate given in the variable FILTR8. Pathogen populations in the soil are altered as a function of soil temperature and moisture content. Three temperature-dependent soil-drying rates have been provided.

j. Crop type affects transfers of pathogens from soil surface water. A fraction of the pathogens in surface soil become suspended in surface water at the beginning of irrigation. Default values for this transfer are estimates. The user may specify supportable values if they are available. While there is standing water in the field, splashing results in transfers

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of pathogens suspended in soil surface water to above-ground crops. On-ground crops are submerged in the irrigation water and retain a portion of suspended pathogens. The number is related to the area of the garden occupied by the crop. Since pathogens suspended in the surface water return to the soil as irrigation water percolates into the soil, below-ground crops received no direct transfers from soil surface water.

k. Workers enter the garden during planting, watering, and harvest and directly remove surface soil which adheres to shoes, clothing, and skin. The default value for direct removal is an estimate of contact.

l. Transfers from subsurface soil to surface soil do not occur when the pathway default values are used. The user may specify transfers to reflect cultivation or other physical disturbance of the soil profile by assigning a value to TRSUR. Specified transfers will occur at weekly intervals.

Compartment Descriptions

Compartment 1, SOIL PREPARATION --

Compost is applied to a residential vegetable-garden plot. The amount is determined by the variables APRATE and GSIZE and the pathogen concentration by the variable ASCRS. The amended soil is manually turned to incorporate the compost and compost-associated pathogens evenly throughout the upper 10 centimeters of soil. This layer is the SOIL SURFACE modeled in Compartment 5. After turning, the garden is planted in one of three crops; an above-ground crop represented by hybrid tomatoes, an on-ground crop represented by zucchini squash, or a below-ground crop represented by carrots. The type of crop is determined by the variable CROP.

This compartment exists primarily to provide for the initial transfers into other compartments. It lasts 12 hours, and no process functions are associated with it. Compost and compost-associated pathogens are transferred from this compartment to Compartment 2, RESIDUE ON EQUIPMENT, by TAU12; to Compartment 3, PARTICULATES, by TAU13; and to Compartment 5, SOIL SURFACE, by TAU15. PARTICULATES are generated during the application and turning activities of the compartment so TAU13 is transferred 1 hour into the pathway. The compost has now been incorporated in the soil and the associated pathogens are being affected by soil conditions. Some compost would be left on the equipment used to spread and incorporate the compost and to plant the crop. Transfer of this residue also occurs at the end of compartment activities, 12 hours into the pathway.

The user may control the amount of sludge transferred to RESIDUE and PARTICULATES by specifying values for the variables WTRES2 and WTPAR3 in the input variable P-array. The number of pathogens associated with the weight of compost transferred is calculated by dividing the weight of compost transferred by the total weight of compost in the compartment from

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which the transfer is being made and then multiplying by the number of pathogens in that compartment. All weights considered in transfers are dry weights since the moisture content of compost or soil may differ in individual pathway runs. Calculations of transfers can always be found in the subroutine for the compartment from which a transfer is made.

Time of first transfer into compartment - Start of pathway.

Time of last transfer out of compartment - 12 hours into pathway.

Process function - RH01
    Activated: Start of pathway.
    Duration: 12 hours.
    Rates: Salmonella: 0.0*N(1)/hour.
        Ascaris: 0.0*N(1)/hour.
        Poliovirus: 0.0*N(1)/hour.

Transfers into compartment -
    TAU01 = ASCIN, Transfer occurs at the start of the pathway.

Transfers out of compartment -
    TAU12 = (WTRES2/(APRATE*GSIZE))*N(1), Transfer occurs 12 hours into pathway.
    TAU13 = (WTPAR3/(APRATE*GSIZE))*N(1), Transfer occurs 1 hour into pathway.
    TAU15 = N(1), Transfer occurs 12 hours into pathway.

Compartment 2, RESIDUE ON EQUIPMENT --

RESIDUE is left on equipment at the end of the SOIL PREPARATION compartment. The amount is determined by the variable WTRES2. The default value for this variable is an estimate. The material in RESIDUE compartments is assumed to dry out rapidly. The process functions assigned to this and other RESIDUE compartments reflect the effects of desiccation on the model pathogens.

Time of first transfer into compartment - 12 hours into pathway.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RH02
    Activated: 12 hours into pathway.
    Duration: Until all pathogens are depleted or the pathway ends.
    Rates: Salmonella: -0.46*N(2)/hour. (8)
        The inactivation of residue-associated salmonella is assumed to occur at the rate for salmonella in drying sludge at greater than 80 percent solids.
        Ascaris: -0.25*N(2)/hour. (22, 40, 74)
        Poliovirus: -0.38*N(2)/hour. (88, 97)

C-5

Transfers into compartment -
TAU12 = (WTRES2/(APRATE*GSIZE))*N(1), Transfer occurs 12 hours into pathway.

Transfers out of compartment - None.

Compartment 3, PARTICULATES --

The activities described for Compartment 1 will generate airborne dust or PARTICULATES. It is assumed in all PARTICULATE compartments that the dust is generated at the start of activities in the compartment from which the transfer to PARTICULATES is made, in this case Compartment 1 -- SOIL PREPARATION, and that the dust and its associated pathogens remain at the initial concentration until the generating activity ceases. The process functions in all PARTICULATES compartments are delayed to allow for maximum inhalation of pathogens during generation activities.

The user may specify the amount of sludge being transferred to this compartment by assigning a value to WTPAR3. There are two compartments described by the title PARTICULATES in this pathway: Compartment 3 and Compartment 4. To avoid confusion in this and other pathways a naming system was used in which the "weight transferred to PARTICULATES" is abbreviated "WTPAR" and the number of the compartment concerned is appended. WTPAR3 being the weight of sludge transferred to PARTICULATES in Compartment 3.

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The default value assigned WTPAR3 was determined by assuming that PARTICULATES are generated to a level of 15 mg/m^3 in a volume extending 10 meters over the 0.015-hectare garden. The concentration of particulates and the height of the volume considered are the same in all PARTICULATES compartments but the area under the dust cloud differs between pathways.

The process functions for PARTICULATES are the same as for RESIDUE and reflect the effects of rapid desiccation of the airborne material and the pathogens associated with it.

Time of first transfer into compartment - 1 hour into pathway.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RHO3
Activated: 12 hours into pathway.
Duration: Until all pathogens are depleted or the pathway ends.
Rates:
Salmonella: -0.46*N(3)/hour. (8)
Ascaris: -0.25*N(3)/hour. (22, 40, 74)
Poliovirus: -0.38*N(3)/hour. (88, 97)

Transfers into compartment -
TAU13 = (WTPAR3/(APRATE*GSIZE))*N(1), Transfer occurs 1 hour into pathway.

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Transfers out of compartment - None.

Compartment 4, PARTICULATES --
This compartment simulates the effects of a windstorm. Dust is blown up from the SOIL SURFACE (TAU54); the amount can be specified by assigning a value to WTPAR4. The default value for this variable assumes 15 milligrams of compost-amended soil per cubic meter of air in a 10-meter high volume above the 0.015-hectare garden. The storm occurs on the fifth day after compost application.

Process functions for this compartment are delayed 12 hours after generation. The rates of inactivation simulate rapid drying.

Time of first transfer into compartment - 120 hours into the pathway.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RHO4
Activated: 142 hours into the pathway.
Duration: Until all pathogens are depleted or the pathway ends.
Rates:
- Salmonella: -0.46*N(4)/hour. (8)
- Ascaris: -0.25*N(4)/hour. (22, 40, 74)
- Poliovirus: -0.38*N(4)/hour. (88, 97)

9-1/8"

Transfers into compartment -
TAU54 = (WTPAR4/(APRATE*GSIZE))*N(5), Transfer occurs 120 hours into the pathway.

Transfers out of compartment - None.

Compartment 5, SOIL SURFACE --
The first 10 centimeters of soil are the SOIL SURFACE. The soil in this compartment is subjected to a moisture cycle which begins 14 hours into the pathway with the first watering of the garden. The soil is at field capacity (20 percent weight/weight) after each watering and between waterings dries as shown in the following figure. Pathogen process functions are tied to the watering cycle. The rate of growth or inactivation of pathogens is dependent on the ambient temperature of the environment and on the available water. The ambient temperature is constant throughout the pathway and is set by the variable TEMP. The available water is a function of the time elapsed since the last watering and the rate of drying which is a function of the ambient temperature.

Compost and pathogens are first transferred into this compartment from the SOIL PREPARATION compartment by TAU15. As the pathway progresses there are several other transfers into this compartment. During each watering, water enters Compartment 9, SURFACE WATER. It then percolates into the soil, transferring pathogens to SOIL SURFACE by TAU59. The pathogens involved in this transfer are either soil pathogens which become

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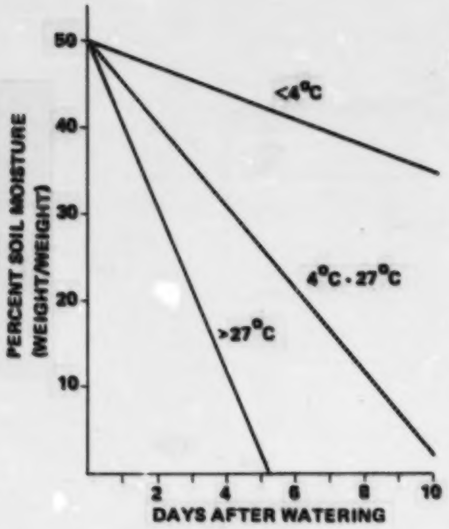

suspended in the water during irrigation, a phenomenon stimulated by TAU59, or may be pathogens introduced from CROP SURFACE. In a similar manner, after pathogens have been transferred to CROP SURFACE, some will be returned to SOIL SURFACE when gravity and wind cause dust on above-ground crops to fall to the ground (TAU85). If the field is cultivated after planting, pathogens which have been carried to SUBSURFACE SOIL (Compartment 7) will be transferred to the SOIL SURFACE as the ground is turned. This is simulated by TAU75.

There is one other way for pathogens to enter this compartment. The user may place an initial pathogen population in any pathway compartment by specifying the compartment number and the desired population in the POPL variable of the $ARGS name list. The mechanism for handling variable specification is fully described in the user's manual for the program (Appendix A). Specifying an initial pathogen population allows the user to examine the effects of several sludge applications. The final compartment populations of one model run would be input as initial populations in the next run. Environmental conditions may be unique for each run, or standard default values may be used.

Pathogens are transferred from this compartment into Compartment 4, PARTICULATES, by TAU54; Compartment 7, SUBSURFACE SOIL, by TAU57; Compartment 8, CROP SURFACE, by TAU58; Compartment 9, SURFACE WATER, by TAU59; and Compartment 6, DIRECT REMOVAL, by TAU56. PARTICULATES are generated by a windstorm that occurs 5 days into the pathway. A further description of the windstorm is found in the preceding description of Compartment 4. The transfer from SOIL SURFACE to SUBSURFACE SOIL occurs after each irrigation as water percolates below the 10-centimeter mark which separates SOIL SURFACE from SUBSURFACE SOIL. The time of this transfer is controlled by the infiltration rate of SURFACE WATER, a parameter the user may specify in

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variable FILTR8. The transfer of soil and soil pathogens to CROP SURFACE is different for each type of crop. As explained in the General Considerations for this pathway, above-ground crops are dusted with soil during the arbitrary windstorm while on-ground and below-ground crops would not be involved in this transfer. At harvest, time THARV, all three types of crops will be contaminated with soil. The fraction of the total pathogen population in Compartment 5 which is transferred to the designated crop is specified in the variables FCROP1, FCROP2, and FCROP3.

Since only one crop is grown in the field during a particular model run, the user must be careful in this pathway to match specified variables to crop type. Inputting a user-specified value in position 13 of the P-array (Table 8b) when running this pathway for CROP = 0.0 (on-ground crop type) will result in the use of the default value for FCROP2 in TAU58. Position 13 is FCROP1, a variable only used when CROP = +1. The user would have to specify the value in position 14 to make a change when looking at on-ground crops. This linking of variables occurs for many parameters.

Soil and soil pathogens are suspended in applied water while it is lying on the surface of the ground and is considered in Compartment 9, SURFACE WATER. This water and its associated pathogens would return to SOIL SURFACE as the irrigation water percolates into the soil. Family members will enter the garden periodically and will carry dirt away with them. This DIRECT REMOVAL is a weekly event until harvest. The variable DIRMOV controls the amount of soil and pathogens transferred to DIRECT REMOVAL.

Time of first transfer into compartment - 12 hours into pathway.

Time of last transfer out of compartment - THARV.

Process function - RHO5
Activated: 12 hours into the pathway.
Duration: Until the end of the pathway.
Rates: Salmonella: 0.0*N(5)/hour, for TEMP < 20.
0.069*N(5)/hour, for 20 < TEMP ≤ 27 and any time until an upper limit specified by the variable UPLIM is reached. (62).
0.069*N(5)/hour, for 27 < TEMP < 45 and time < 60 hours after watering until the upper limit set by UPLIM is reached. (62)
-0.012*N(5)/hour, for 27 < TEMP < 45 and time > 60 hours after watering. (23, 72, 73)
-3.45*N(5)/hour, for TEMP ≥ 45 and any time. (8, 93)
Ascaris: -0.00053*N(5)/hour, for TEMP < 40. (83)
-1.535*N(5)/hour, for TEMP > 40. (7,78)
Poliovirus: -0.00087*N(5)/hour, for TEMP < 15. (96)
-0.0049*N(5)/hour, for 15 < TEMP < 45. (27, 96)
-0.38*N(5)/hour, for TEMP ≥ 45. (88, 97)

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Transfers into compartment -

TAU15 = N(1), Transfer occurs 12 hours into the pathway.

TAU75 = TRSUR*N(7), Transfer occurs at 7-day intervals from 168 hours if TRSUR is set to a positive value.

TAU85 (above-ground crop) = TCSSS*N(8), Transfer occurs at 7-day intervals from 15 hours and at THARV.

TAU85 (other crops) = 0.0*N(8), Transfer occurs at THARV.

TAU95 = N(9) - TAU98, Transfer occurs at 72-hour intervals from 14 hours = (DEPTH/FILTR8).

Transfers out of compartment -

TAU54 = (WTPAR4/(APRATE*GSIZE))*N(5), Transfer occurs 120 hours into the pathway.

TAU56 = (DIRMOV/(APRATE*GSIZE))*N(5), Transfer occurs at 7-day intervals from 13 hours and at THARV.

TAU57 = TRSUB*N(5), Transfer occurs at 72-hour intervals from 15 hours + (DEPTH/FILTR8).

TAU58 (above-ground crop) = FCROP1*N(5), Transfer occurs at 7-day intervals from 13 hours and at THARV.

TAU58 (on-ground crop) = FCROP2*N(5), Transfer occurs at THARV.

TAU58 (below-ground crop) = FCROP3*N(5), Transfer occurs at THARV.

TAU59 = TRNSUR*N(5), Transfer occurs at 72-hour intervals from 14 hours into the pathway.

Compartment 6, DIRECT REMOVAL --

Surface soil and the pathogens associated with it will adhere to the shoes, clothing, and skin of people who work in the garden. These pathogens are directly removed from the area. DIRMOV is the variable which determines the weight of soil transferred from SOIL SURFACE to DIRECT REMOVAL once each week. No change occurs in the pathogen populations for 24 hours after removal; then the populations are set to zero. This allows for possible ingestion of compost-amended soil.

Time of first transfer into compartment - 14 hours into pathway.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted following the last transfer into the compartment.

Process function - RHO6

Activated: 14 hours into pathway, then at weekly intervals until harvest (THARV) and at harvest.

Duration: 24 hours after each transfer.

Rates:
Salmonella: N(6) = 0.0 after 24 hours.
Ascaris: N(6) = 0.0 after 24 hours.
Poliovirus: N(6) = 0.0 after 24 hours.

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Transfers into compartment -

TAU56 = (DIRMOV/APRATE*GSIZE))*N(5), Transfer occurs 14 hours into the pathway and then at weekly intervals until THARV.

Transfers out of compartment - None.

Compartment 7, SUBSURFACE SOIL --

This compartment represents the soil from 10 to 60 centimeters below the surface. This SUBSURFACE SOIL is at constant moisture (field capacity, 20 percent weight/weight) and temperature (15°C). Pathogens from the compost-amended upper 10 centimeters of soil are transferred into this compartment with percolating irrigation water. The fraction of the total SOIL SURFACE (Compartment 5) pathogen population transferred is determined by the variable TRSUB. The time of the transfer by TAU57 is controlled by the depth of irrigation water which must soak in (DEPTH) and the rate of water infiltration (FILTR8), but the transfer occurs after each irrigation.

There are three possible transfers out of this compartment. Pathogens may be transferred to Compartment 5, SOIL SURFACE, by TAU75 if the user specifies a positive value for the variable TRSUR. This variable indicates that cultivation is to be simulated and sets the fraction of transfer. Cultivation, once flagged, occurs at weekly intervals. Pathogens may be transferred to Compartment 8, CROP SURFACE, by TAU78 if the below-ground crop type is being modeled. This transfer would occur at harvest.

A fraction of the pathogens which did not transfer out of this compartment in the transfers listed above becomes part of the SOIL SINK at harvest. The SOIL SINK is not defined as a compartment in this model. The variable SINK specifies the fraction transferred.

Time of first transfer into compartment - 14 hours + (DEPTH/FILTR8).

Time of last transfer out of compartment - THARV.

Process function - RHO7

Activated:	14 hours + (DEPTH/FILTR8)	
Duration:	Until THARV.	
Rates:	Salmonella:	-0.012*N(7)/hour. (23, 72, 73)
	Ascaris:	-0.00053*N(7)/hour. (83)
	Poliovirus:	-0.0049*N(7)/hour. (27, 96)

Transfers into compartment -

TAU57 = TRSUB*N(5), Transfer occurs at 72-hour intervals from 14 hours + (DEPTH/FILTR8).

Transfers out of compartment -

TAU70 = SINK*N(7), Transfer occurs at the end of the pathway.

TAU75 = TRSUR*N(7) = Transfer occurs at 7-day intervals from 168 hours if TRSUR is set to a positive value.

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TAU78 (below-ground crop) = FCROP7*N(7), Transfer occurs at THARV.
TAU78 (other crops) = 0.0, Transfer occurs at THARV.

Compartment 8, CROP SURFACE --
Before each pathway run the user must specify one crop type. The default value for the variable CROP specifies the above-ground type represented by bush tomatoes. An on-ground crop represented by zucchini squash and a below-ground crop represented by carrots are the other choices. The crop types are described in the General Considerations for this pathway (items e and g). Table 1c presents a convenient summary of the parameters defining each crop.

The type of crop controls the transfers into and out of this compartment. Above-ground crops contact pathogens in dust generated from the SOIL SURFACE, a transfer modeled by TAU58 which occurs weekly, and from SURFACE WATER which splashes up during irrigation, a transfer modeled by TAU98. On-ground crops are not affected by blown dust since they are essentially at equilibrium with surface soil but the transfer from SURFACE WATER is greater than for above-ground crops. On-ground crops are covered by water during each irrigation. Below-ground crops lie half in the surface soil and half in the subsurface soil. No dust or irrigation water reaches them. All three crops contact pathogens transferred from SOIL SURFACE by TAU58 at harvest. This represents the normal dirt found on all fresh vegetables. Only below-ground crops also receive a transfer from SUBSURFACE SOIL by TAU78. At THARV all pathogens associated with crops are transferred to Compartment 10, HARVESTING AND STORAGE.

Time of first transfer into compartment - 14 hours into pathway.

Time of last transfer out of compartment - THARV.

Process function - RHO8
Activated: 14 hours into pathway.
Duration: Until THARV.
Rates: Salmonella: -0.096*N(8)/hour, for above-ground and on-ground crops. (72, 73)
0.0*N(8)/hour, for below-ground crops.
Ascaris: -1.54*N(8)/hour, for above-ground and on-ground crops. (7, 78)
0.0*N(8)/hour, for below-ground crops.
Poliovirus: -0.069*N(8)/hour, for above-ground and on-ground crops. (49)
0.0*N(8)/hour, for below-ground crops.

Transfers into compartment -
TAU58 (above-ground crop) = FCROP1*N(5), Transfer occurs at 7-day intervals from 13 hours and at THARV.
TAU58 (on-ground crop) = FCROP2*N(5), Transfer occurs at THARV.
TAU58 (below-ground crop) = FCROP3*N(5), Transfer occurs at THARV.

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TAU78 (below-ground crop) = FCROP7*N(7), Transfer occurs at THARV.
TAU78 (other crops) = 0.0, Transfer occurs at THARV.
TAU98 (above-ground crop) = FCROP4*N(9), Transfer occurs at 72-hour intervals from 14 hours + (DEPTH/FILTR8).
TAU98 (on-ground crop) = FCROP5*N(9), Transfer occurs at 72-hour intervals from 14 hours + (DEPTH/FILTR8).
TAU98 (below-ground crop) = FCROP6*N(9), Transfer occurs at 72-hour intervals from 14 hours + (DEPTH/FILTR8).

Transfers out of compartment -
TAU85 (above-ground crop) = TCSSS*N(8), Transfer occurs at 7-day intervals from 15 hours and at THARV.
TAU85 (other crops) = 0.0, Transfer occurs at THARV.
TAU89 (on-ground crop) = N(8), Transfer occurs at 72-hour intervals from 14 hours.
TAU89 (other crops) = 0.0, Transfer occurs at 72-hour intervals from 14 hours.
TAU810 = N(8), Transfer occurs at THARV.

Compartment 9, SURFACE WATER --

Watering in this model involves flooding the garden with water to a uniform depth (specified by the variable DEPTH) and then allowing the water to infiltrate the soil at a constant rate (specified by the variable FILTR8). Pathogens in SOIL SURFACE and on the CROP SURFACE of on-ground crops will become suspended in the overlying water. These transfers from Compartment 5 and Compartment 8, respectively, will occur for each watering.

Pathogens transfer back to Compartment 5, SOIL SURFACE, and Compartment 8, CROP SURFACE, when the irrigation water soaks into the soil. Although this would normally be a gradual process, TAU95 and TAU98 occur at the end of each irrigation, as a single transfer to each compartment.

Time of first transfer into compartment - 14 hours into pathway, at the first irrigation.

Time of last transfer out of compartment - Transfers are made from this compartment following each irrigation. The last transfer will follow the last irrigation before harvest. The exact time depends on the value of THARV.

Process function - RHO9
Activated: At the start of each watering.
Duration: DEPTH/FILTR8.
Rates: Salmonella: 0.23*N(9)/hour. A 3-hour generation time is assumed for growth of salmonella suspended in irrigation water.
Ascaris: 0.0*N(9)/hour.

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Poliovirus: 0.0*N(9)/hour. No change is assumed for ascaris and poliovirus suspended in irrigation water.

Transfers into compartment -
TAU59 = TRNSUR*N(5), Transfer occurs at 72-hour intervals from 14 hours into the pathway.
TAU89 (on-ground crop) = N(7), Transfer occurs at 72-hour intervals from 14 hours.
TAU89 (other crops) = 0.0, Transfer occurs at 72-hour intervals from 14 hours.

Transfers out of compartment -
TAU95 = N(9) - TAU98, Transfer occurs at 72-hour intervals from 14 hours + (DEPTH/FILTR8).
TAU98 (above-ground crop) = FCROP4*N(9), Transfer occurs at 72-hour intervals from 14 hours + (DEPTH/FILTR8).
TAU98 (on-ground crop) = FCROP5*N(9), Transfer occurs at 72-hour intervals from 14 hours + (DEPTH/FILTR8).
TAU98 (below-ground crop) = FCROP6*N(9), Transfer occurs at 72-hour intervals from 14 hours + (DEPTH/FILTR8).

Compartment 10, HARVESTING AND STORAGE --

This compartment was originally designed to simulate harvesting of the crop and those processes which are often a part of handling raw vegetables, such as storage and washing. These processes are now included in vegetable-exposure risk calculations discussed in Section 6. No process functions are defined here. Pathogens are transferred into this compartment from Compartment 8, CROP SURFACE, by TAU810. The transfer represents the physical removal of mature crops from the garden, or harvest. This occurs at the user-specified time of harvest, THARV. The calculations necessary to determine the number of pathogens per crop unit of harvested vegetables are performed in this compartment. This number is output in position 27 of Pathway 8's P-array. It is this number which is used by the vegetable-exposure risk calculations.

Significant calculations - The number of pathogens per crop unit (FPCU) equals:
N(10)/983, for above-ground crops
N(10)/600, for on-ground crops
N(10)/1967, for below-ground crops.

A crop unit is one tomato, zucchini, or carrot. The number in the numerator of the fractions listed above is the number of crop units which would be grown in the 0.015-hectare garden when the assumptions as to size and plant spacing listed in Table 4c are considered.

Time of first transfer into compartment - THARV.

Time of last transfer out of compartment - There are no transfers out of this compartment, which is the last in the pathway. Consideration of the compartment ends when the pathway terminates.

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Process function - RHO10
Activated: THARV
Duration: Until the pathway ends (26 hours).
Rates: Salmonella: 0.0*N(10)/hour.
Ascaris: 0.0*N(10)/hour.
Poliovirus: 0.0*N(10)/hour.

No process functions are defined for this compartment. The compartment was originally designed to simulate the effects of domestic food processing on pathogens. These processes are now part of the vegetable-consumption risk calculation.

Transfers into compartment -
TAU810 = N(8), Transfer occurs at THARV.

Transfers out of compartment - None.

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PATHWAY 9 - SLUDGE APPLICATION PATHWAY - RESIDENTIAL LAWN SOIL AMENDMENT

General Considerations

This pathway describes the fate of sewage sludge pathogens after the use of composted sludge during the planting of a new residential lawn. Figure 9 shows the process compartments and transfers which define this application regime. The differential equations which describe this pathway are presented in Table 9a. Each process and transfer function is defined in the following section. Table 9b lists the definitions of and default values for the input variables used to define environmental factors which affect process and transfer functions. The model user may supply a value for any input variable and, thus, set the program to model a specific situation of concern. The general considerations and assumptions discussed below were made to facilitate model development.

a. The pathway is divided into four seasonal periods. The user may specify the duration and ambient temperature of each season. Under default conditions, the model runs for 360 days broken into 90 day seasons. The ambient temperature for the first 90-day period is 20°C, the second - 5°C, the third - 20°C, and the fourth - 35°C. These temperatures approximate a fall-winter-spring-summer seasonal progression. The value assigned to TFALL, the variable which controls the duration of the first period, must be greater than the 35 days required for planting, germination and first mowing of the lawn. The values assigned to each of the variables controlling the termination of the other seasonal periods must be successively larger so that each season ends at a later time than the season which proceeded it.

b. The amount of compost applied to the lawn (APRATE) and the concentration of pathogens in that compost (ASCRS) are user-specifiable variables. The model allows one application of composted sludge, which is turned into the soil before the lawn is seeded. There are no additional applications of sludge. Default values are based on the application rate for composted steer manure to a new lawn in the Southwest (25) and are equal to 2 cubic yards of compost per 1000 square feet of lawn. The default values for the number of pathogens present in the compost reflect a conservative "worst case" and are set equal to the concentration of each pathogen in raw sludge from a municipal treatment system (1, 4, 28, 32, 77). The value of the output variable NPKC in position 67 of Pathway 3's P-array is equal to the number of pathogens per kilogram of compost at the end of a run of Pathway 3. The user may run Pathway 3 for one of the three pathogens and then use the output value of NPKC as the value for ASCRS, the variable in position 1 of Pathway 9's P-array. ASCRS determines the number of pathogens per kilogram of compost applied to the lawn. In this way Pathways 3 and 9 may be linked and a selected pathogen followed through treatment and application of sludge.

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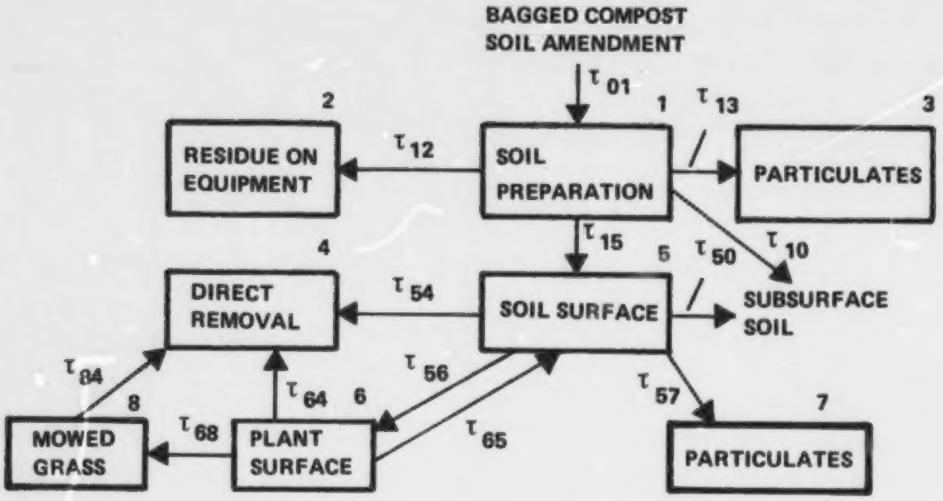
BAGGED COMPOST
SOIL AMENDMENT
τ_{01}
1
SOIL PREPARATION
τ_{12}
2
RESIDUE ON EQUIPMENT
τ_{13}
3
PARTICULATES
τ_{15}
τ_{10}
5
SOIL SURFACE
τ_{50}
SUBSURFACE SOIL
τ_{54}
4
DIRECT REMOVAL
τ_{56}
τ_{65}
6
PLANT SURFACE
τ_{64}
τ_{68}
8
MOWED GRASS
τ_{84}
τ_{57}
7
PARTICULATES

Figure 9. Sludge Application Pathway - Residential Lawn Soil Amendment

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TABLE 9a. DIFFERENTIAL EQUATIONS FOR PATHWAY 9

SLUDGE APPLICATION PATHWAY - RESIDENTIAL LAWN SOIL AMENDMENT

$$\dot{N}_1 = \tau_{01} - \tau_{10} - \tau_{12} - \tau_{13} - \tau_{15} + \rho_1$$

$$\dot{N}_2 = \tau_{12} + \rho_2$$

$$\dot{N}_3 = \tau_{13} + \rho_3$$

$$\dot{N}_4 = \tau_{54} + \tau_{64} + \tau_{84} + \rho_4$$

$$\dot{N}_5 = \tau_{15} + \tau_{65} - \tau_{50} - \tau_{54} - \tau_{56} - \tau_{57} + \rho_5$$

$$\dot{N}_6 = \tau_{56} - \tau_{64} - \tau_{65} - \tau_{68} + \rho_6$$

$$\dot{N}_7 = \tau_{57} + \rho_7$$

$$\dot{N}_8 = \tau_{68} - \tau_{84} + \rho_8$$

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TABLE 9b. VARIABLES FOR PATHWAY 9

SLUDGE APPLICATION PATHWAY - RESIDENTIAL LAWN SOIL AMENDMENT

POSITION	DEFAULT VALUE	VARIABLE	DEFINITION
		INPUT VARIABLES	
1	1.95E+7 4.95E+2 6.52E+7	ASCRS	Number of pathogens per kilogram of applied compost.
2	4.409E+3	APRATE	Application rate of compost in kilograms per 0.05 hectares.
3	ASCRS*APRATE	ASCIN	Total number of pathogens entering pathway. If present, overrides first two variables.
4	0.075	WTPAR3	Dry weight in kilograms of particulates generated in Compartment 3.
5	0.5	WTRES2	Dry weight in kilograms of compost transferred to Residue in Compartment 2.
6	0.4	FRTSUR	Fraction of pathogens transferred from Soil Preparation to Soil Surface.
7	20.	TEMPF	Ambient temperature during the first seasonal period (fall).
8	5.	TEMPW	Ambient temperature during the second seasonal period (winter).
9	20.	TEMPS	Ambient temperature during the third seasonal period (spring).
10	35.	TEMPSU	Ambient temperature during the fourth seasonal period (summer).
11	2160.	TFALL	Termination time of first seasonal period (fall). Must be >840 hours.

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TABLE 9b. (continued)

POSITION	DEFAULT VALUE	VARIABLE	DEFINITION
12	4320.	TWINTR	Termination time of second seasonal period (winter). Must be J TFALL.
13	6480.	TSPRNG	Termination time of the third seasonal period (spring). Must be J TWINTR.
14	8640.	TSUMR	Termination time of fourth seasonal period (summer). Must be J TSPRING. Also specifies length of the pathway.
15	0.0005 0.00001 0.1	FRSINK	Fraction of pathogens transferred from Soil Surface to Soil Sink.
16	0.075	WTPAR7	Dry weight in kilograms of particulates generated by windstorm in Compartment 7.
17	0.5	REMWT	Weight of soil in kilograms transferred to Direct Removal from Soil Surface.
18	0.2	FRPLNT	Fraction of pathogens transferred from Soil Surface to Plant Surface.
19	0.1	FRDRT	Fraction of pathogens transferred from Plant Surface to Soil Surface.
20	0.1	FREM	Fraction of pathogens transferred from Plant Surface to Direct Removal.
21	0.1	GRAREM	Fraction of pathogens transferred to Direct Removal from Mowed Grass.
22	0.5	PSTMG	Fraction of pathogens transferred from Plant Surface to Mowed Grass.

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TABLE 9b. (concluded)

NOTES: The number of pathogens per day entering the pathway will default to APRATE*ASCRS if no value is specified for ASCIN. If a value is specified for ASCIN, it will override the APRATE*ASCRS value.

Whenever three default values are specified for any variable in the list above, the order is salmonellae, ascaris, poliovirus pathogen types. The appropriate default value will be selected to agree with the pathogen type being considered in a particular run.

All units of measure are in kilograms, degrees Celsius, or hours unless otherwise stated.

Variables labeled "output" are for internal computations and are not available to the user as input.

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c. The area of the lawn is set at 0.05 hectares. This is approximately one-eighth of an acre and reflects the size of an average suburban yard.

d. At the time of application, compost is turned into the soil and the upper 10 centimeters of soil become a homogeneous mixture of compost and soil. The model divides this area into two distinct layers. The soil surface layer extends 4 centimeters down and is subject to temperature and moisture fluctuations. People working or playing on the lawn would normally come into contact with this layer. The subsurface soil sink lies below the soil surface layer and represents an area where pathogens are removed from possible contact.

e. The newly seeded lawn is kept constantly moist for five weeks. This period includes germination of the seed and the first mowing of the lawn. After the fifth week, the lawn is watered every other day and it is mowed once a week.

f. Particulates are generated during soil preparation and are blown up from the soil surface on day 5 to simulate the effects of a windstorm. As in other pathways, default values assume 15 milligrams of dust per cubic meter in a 10-meter high volume above the 0.05-hectare surface of the lawn.

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g. Pathogen populations in the soil surface will be altered (growth or inactivation) as a function of soil temperature or moisture content. The temperature will remain constant during each season. Because soil dryness is also related to temperature, three drying rates for the soil surface have been provided. The first rate describes soil moisture changes with time at temperatures less than 4°C, the second describes soil moisture changes between 4°C and 27°C, and the third describes soil moisture changes at temperatures greater than 27°C.

Compartment 1, SOIL PREPARATION--

Compost is applied to a residential yard as part of the soil preparation for a new lawn. The amount applied is determined by the variable APRATE and the pathogen concentration by the variable ASCRS. The amended soil is manually turned to incorporate the compost and compost-associated pathogens evenly throughout the upper 10 centimeters of soil. The soil is divided into two areas: the SOIL SURFACE modeled in Compartment 5 and the SUBSURFACE SOIL SINK which is not treated as a compartment within this model. After the compost is incorporated into the soil, a lawn is seeded and the soil wetted.

This compartment exists primarily to provide for the initial transfers into other compartments. It last 12 hours and there are no process functions associated with it. Compost and compost-associated pathogens are transferred from this compartment to Compartment 2, RESIDUE ON EQUIPMENT, by TAU12; to Compartment 3, PARTICULATES, by TAU13; to Compartment 5, SOIL SURFACE, by TAU15; and to the SUBSURFACE SOIL SINK.

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Particulates are generated during the application of compost and its subsequent incorporation into the soil. TAU13 occurs 1 hour into the pathway. The transfers to SOIL SURFACE and SUBSURFACE SOIL SINK mark the end of SOIL PREPARATION, 12 hours into the pathway. Compost has now been incorporated into the soil and its associated pathogens are being affected by soil conditions. Some compost and soil would be left on the tools used to spread and incorporate the compost and to seed and roll the lawn. Transfer of this residue also occurs at the end of compartment activities, 11 hours into the pathway.

The user may control the amount of sludge transferred to RESIDUE and PARTICULATES by specifying values for the variables WTRES2 and WTPAR3 in the input variable P-array. The number of pathogens associated with the weight of compost transferred is calculated by dividing the weight of compost transferred by the total weight of compost in the compartment from which the transfer is being made and then multiplying by the number of pathogens in that compartment. All weights considered in transfers are dry weights since the moisture content of compost or soil may differ in individual pathway runs. Calculations of transfers can always be found in the subroutine for the compartment from which a transfer is made.

Time of first transfer into compartment - Start of pathway.

Time of last transfer out of compartment - 12 hours into pathway.

Process function - RH01
  Activated: Start of pathway.
  Duration: 12 hours.
  Rates: Salmonella: 0.0*N(1)/hour.
    Ascaris: 0.0*N(1)/hour.
    Poliovirus: 0.0*N(1)/hour.

Transfers into compartment -
  TAU01 = ASCIN, Transfer occurs at the start of the pathway.

Transfers out of compartment -
  TAU10 = (1. - FRTSUR)*N(1), Transfer occurs 12 hours into the pathway.
  TAU12 = (WTRES2/(APRATE - WTPAR3))*N(1), Transfer occur 11 hours into the pathway.
  TAU13 = (WTPAR3/APRATE)*N(1), Transfer occurs 1 hour into the pathway.
  TAU15 = FRTSUR*N(1), Transfer occurs 12 hours into the pathway.

Compartment 2, RESIDUE ON EQUIPMENT --

RESIDUE is left on equipment at the end of the SOIL PREPARATION compartment. The amount is determined by the variable WTRES2. The default value for this variable is an estimate. The material in RESIDUE compartments is assumed to dry out rapidly. The process functions assigned to this and other RESIDUE compartments reflect the effects of desiccation on the model pathogens.

Time of first transfer into compartment - 11 hours into pathway.

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Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RHO2
Activated: 11 hours into pathway.
Duration: Until all pathogens are depleted or the pathway ends.
Rates: Salmonella: -0.46*N(2)/hour. (8)
The inactivation of residue-associated salmonella is assumed to occur at the rate for salmonella in drying sludge at greater than 80 percent solids.
Ascaris: -0.25*N(2)/hour. (22, 40, 74)
Poliovirus: -0.38*N(2)/hour. (88, 97)

Transfers into compartment -
TAU12 = (WTRES2/(APRATE - WTPAR3))*N(1), Transfer occurs 11 hours into pathway.

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Transfers out of compartment - None.

Compartment 3, PARTICULATES --

The activities described for Compartment 1 will generate airborne dust or PARTICULATES. It is assumed in all PARTICULATES compartments that the dust is generated at the start of activities in the compartment from which the transfer to PARTICULATES is made, in this case Compartment 1 - SOIL PREPARATION, and that the dust and its associated pathogens remain at the initial concentration until the generating activity ceases. The process functions in all PARTICULATES compartments are delayed to allow for maximum inhalation of pathogens during generation activities.

The user may specify the amount of sludge being transferred to this compartment by assigning a value to WTPAR3. There are two compartments described by the title PARTICULATES in this pathway: Compartment 3 and Compartment 7. To avoid confusion in this and other pathways a naming system was used in which the "weight transferred to PARTICULATES" is abbreviated "WTPAR" and the number of the compartment concerned is appended, WTPAR3 being the weight of sludge transferred to PARTICULATES in Compartment 3.

The default value assigned WTPAR3 was determined by assuming that PARTICULATES are generated to a level of 15 mg/m^3 in a volume extending 10 meters over the 0.05-hectare lawn. The concentration of particules and the height of the volume considered are the same in all PARTICULATES compartments but the area under the dust cloud differs between pathways.

The process functions for PARTICULATES are the same as for RESIDUE and reflect the effects of rapid desiccation of the airborne material and the pathogens associated with it.

Time of first transfer into compartment - 1 hour into pathway.

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Time of last transfer out of compartment - There are no transfers out of the compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RHO3
Activated: 12 hours into pathway.
Duration: Until all pathogens are depleted or the pathway ends.
Rates: Salmonella: -0.46*N(3)/hour. (8)
Ascaris: -0.25*N(3)/hour. (22, 40, 74)
Poliovirus: -0.38*N(3)/hour. (88, 97)

Transfers into compartment -
TAU13 = (WTPAR3/APRATE)*N(1), Transfer occurs 1 hour into pathway.

Transfers out of compartment - None.

Compartment 4, DIRECT REMOVAL --

Soil and soil-associated pathogens will adhere to the shoes, clothing, and skin of those who work and play on the lawn. These pathogens are directly removed from the lawn and might be ingested by those who came into contact with the compost-amended soil. The first transfer to DIRECT REMOVAL is from SOIL SURFACE (TAU54) at the time the lawn is seeded. After the lawn is green, further transfers are made from PLANT SURFACE (TAU64) to simulate playing on the lawn and from MOWED GRASS (TAU84) to simulate contact with grass clippings, etc. The fraction of the total pathogen population in Compartments 6 and 8 which will be transferred to DIRECT REMOVAL is determined by the variables FREM and GRAREM, respectively. The variable REMWT determines the weight of soil removed during seeding. No process functions are defined for this compartment. Transferred pathogens are assumed to remain unchanged for 24 hours. Then the population is set to zero.

Time of first transfer into compartment - 14 hours into the pathway.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RHO4
Activated: 24 hours after each transfer in.
Duration: 1 hour.
Rates: Salmonella: -N(4)/hour after 24 hours.
Ascaris: -N(4)/hour after 24 hours.
Poliovirus: -N(4)/hour after 24 hours.

Transfers into compartment -
TAU54 = (REMWT/(FRTSUR*(APRATE - WTRES2 - WTPAR3)))*N(5), Transfer occurs 14 hours into the pathway.
TAU64 = FREM*N(6), Transfer occurs at 24-hour intervals from 240 hours.

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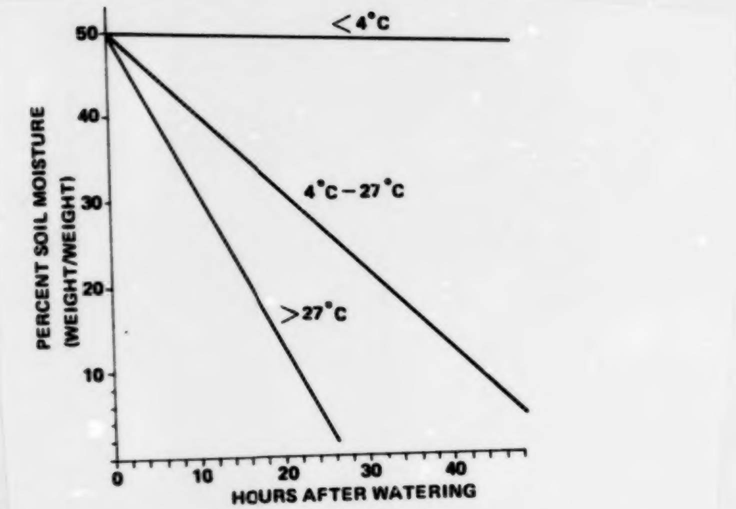
TAU84 = GRAREM*N(8), Transfer occurs at weekly intervals from 840 hours.

Transfers out of compartment - None.

Compartment 5, SOIL SURFACE --

The upper 4 centimeters of soil under the lawn is the SOIL SURFACE. Pathogens are initially transferred into this compartment from SOIL PREPARATION when compost is worked into the soil. When the lawn is seeded a transfer (TAU54) is made from SOIL SURFACE to DIRECT REMOVAL. The user may specify a value for REMWT, the variable which determines the weight of compost-amended soil removed on hands, shoes and clothing. The lawn is watered lightly twice a day after seeding until it is mowed for the first time at 840 hours. This regime will keep the soil constantly moist during the pre-mown period. A fraction of soil-associated pathogens will be transferred to the SUBSURFACE SOIL SINK by each watering (TAU50). After the lawn is mowed for the first time, it is only watered every other day. The soil will dry at the rates shown in the following figure between waterings. The transfer described by TAU50 also changes. It now occurs at 48-hour intervals to agree with the new watering schedule but it is assumed that twice as many pathogens are transferred each time because each watering is heavier and will penetrate further. The variable FRSINK determines the number of pathogens transferred from SOIL SURFACE to SUBSURFACE SOIL SINK.



When the newly seeded grass pushes up through the soil, it will take with it a fraction of the total soil pathogen population which is defined by the variable FRPLNT. The first transfer from SOIL SURFACE to PLANT SURFACE (TAU56) occurs at 240 hours when to lawn shows "first green." Thereafter, one-tenth of FRPLNT is transferred to Compartment 6 each day while a fraction of the grass-associated pathogens falls back to the soil. The transfer from PLANT SURFACE (Compartment 6) to SOIL SURFACE is shown

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in TAU65 where FRDRT is the variable controlling the number of pathogens returning to the soil.

There is one other transfer of pathogens from SOIL SURFACE. During the fifth day after the lawn is seeded, before the grass is up, a windstorm raises dust from the uncovered soil. This transfer to Compartment 7, PARTICULATES, by TAU57 is controlled by the variable WTPAR7. The default value for this variable would permit the generation of 15 milligrams of dust in every cubic meter of air in a 10-meter high volume above the 0.05-hectare lawn.

Time of first transfer into compartment - 12 hours into pathway.

Time of last transfer out of compartment - Transfers are made from this compartment daily. The time of the last transfer depends upon the user-specified pathway duration.

Process function - RH05
  Activated: 12 hours into the pathway.
  Duration: Until the end of the pathway.
  Rates: Salmonella:

a. When time $\le$ 840 hours into the pathway;
   0.069*N(5)/hour, for $20 < TEMP \le 45$ to an upper limit of 1×10^6 salmonella per gram of compost-amended soil. The growth of salmonella is assumed to occur at one-half the rate for salmonella in sterile compost. (62)
   -3.45*N(5)/hour, for $45 < TEMP$. (8, 93)
   0.0*N(5)/hour, for $20 > TEMP$. No changes in pathogen population are assumed for temperatures less than 20°C.

b. When time > 840 hours into the pathway;
   0.0*N(5)/hour, for $4 > TEMP$.
   0.0*N(5)/hour, for $4 \le TEMP < 20$ and 0-40 hours have elapsed since watering.
   -0.46*N(5)/hour, for $4 \le TEMP < 20$ and 40-48 hours have elapsed since watering. (8)
   0.069*N(5)/hour, for $20 \le TEMP \le 27$ and 0-26 hours have elapsed since watering, to an upper limit of 1×10^6 per gram of soil. (62)
   -0.012*N(5)/hour, for $20 \le TEMP \le 27$ and 26-40 hours have elapsed since watering. (23, 72, 73)
   -0.46*N(5)/hour, for $20 \le TEMP \le 27$ and 40-48 hours have elapsed since watering. (8)
   0.069*N(5)/hour, for $27 < TEMP < 45$ and 0-14 hours have elapsed since watering,

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to an upper limit of 1×10^6 per gram of soil. (62)
-0.012*N(5)/hour, for $27 < TEMP < 45$ and 14-20 hours have elapsed since watering. (23, 72, 73)
-0.46*N(5)/hour, for $27 < TEMP < 45$ and 20-48 hours have elapsed since watering. (8)
-3.45*N(5)/hour, for $45 \geq TEMP$ or more than 48 hours have elapsed since watering. (8, 93)

Ascaris:

a. When time < 840 hours into the pathway;
-0.00042*N(5)/hour, for $40 > TEMP$. (22, 31, 32, 70)
-1.54*N(5)/hour, for $40 < TEMP$. (7, 78)

b. When time > 840 hours into the pathway;
-0.00042*N(5)/hour, for $4 > TEMP$. (22, 31, 32, 70)
-0.00042*N(5)/hour, for $4 \leq TEMP \leq 27$ and 0-40 hours have elapsed since watering. (22, 31, 32, 70)
-0.25*N(5)/hour, for $4 \leq TEMP \leq 27$ and 40-48 hours have elapsed since watering. (22, 40, 74)
-.00053*N(5)/hour, for $27 < TEMP < 40$ and 0-20 hours have elapsed since watering. (83)
-0.25*N(5)/hour, for $27 < TEMP < 40$ and 20-48 hours have elapsed since watering. (22, 40, 74)
-1.54*N(5)/hour, for $40 \leq TEMP$ or more than 48 hours have elapsed since watering. (7, 78)

Poliovirus:

a. When time < 840 hours into the pathway;
-0.00087*N(5)/hour, for $15 > TEMP$. (96)
-0.0049*N(5)/hour, for $15 \leq TEMP < 45$. (27, 96)
-0.38*N(5)/hour, for $45 \leq TEMP$. (88, 97)

b. When time > 840 hours into the pathway;
-0.00087*N(5)/hour, for $4 > TEMP$ and 0-48 hours have elapsed since watering. (96)
-0.00087*N(5)/hour, for $4 \leq TEMP \leq 15$ and 0-40 hours have elapsed since watering. (96)
-0.027*N(5)/hour, for $4 \leq TEMP \leq 15$ and 40-48 hours have elapsed since watering. (87, 96)

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-0.0049*N(5)/hour, for 15 < TEMP ≤ 27 and 0-40 hours have elapsed since watering. (87, 96)

-0.027*N(5)/hour, for 15 < TEMP ≤ 27 and 40-48 hours have elapsed since watering. (87, 96)

-0.0049*N(5)/hour, for 27 < TEMP < 45 and 0-20 hours have elapsed since watering. (87, 96)

-0.027*N(5)/hour, for 27 < TEMP < 45 and 20-48 hours have elapsed since watering. (87, 96)

-0.38*N(5)/hour, for 45 ≤ TEMP or more than 48 hours have elapsed since watering. (88, 97)

TEMP = TEMPF, TEMPW, TEMPS, TEMPSU

Transfers into compartment -

TAU15 = FRTSUR*N(1), Transfer occurs 12 hours into the pathway.

TAU65 = FRDRT*N(6), Transfer occurs at 24-hour intervals from 240 hours into the pathway.

Transfers out of compartment -

TAU50 (time < 840 hours) = FRSINK*N(5), Transfer occurs at 12-hour intervals from 14 hours until 840 hours into the pathway.

TAU50 (time ≥ 840 hours) = 2*FRSINK*N(5), Transfer occurs at 48-hour intervals from 840 hours.

TAU54 = (REMWT/(FRTSUR*(APRATE - WTRES2 - WTPAR3)))*N(5), Transfer occurs 14 hours into the pathway.

TAU56 (time = 240 hours) = FRPLNT*N(5), Transfer occurs 240 hours into the pathway.

TAU56 (time > 240 hours) = 0.1*FRPLNT*N(5), Transfer occurs at 24-hour intervals from 264 hours into the pathway.

TAU57 = (WTPAR7/(FRTSUR*(APRATE - WTRES2 - WTPAR3)))*N(5), Transfer occurs 120 hours into the pathway.

Compartment 6, PLANT SURFACE --

The lawn is seeded during the first 12 hours of a pathway run. Ten days later (240 hours into the pathway) the lawn shows its "first green." As grass shoots push up through the soil, pathogens from the compost worked into that soil will contact the PLANT SURFACE. This transfer from Compartment 5, SOIL SURFACE, is controlled by the variable FRPLNT. Each day after first green one-tenth of the fraction of total soil pathogens specified by FRPLNT is transferred to PLANT SURFACE, simulating dust blown up onto the grass blades.

Every day after first green there is a transfer of grass-associated pathogens to DIRECT REMOVAL (TAU64) and SOIL SURFACE (TAU65) as people walk across and play on the lawn and as wind and gravity return dust to the ground. These transfers are controlled by the variables FREM and FRDRT. Five weeks (840 hours into the pathway) after the lawn was seeded,

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it is ready to be mowed for the first time. It is mowed once a week thereafter. At each mowing the upper portion of the PLANT SURFACE is removed and with it a corresponding fraction of the pathogens in this compartment. This fraction, specified by the variable PSTMG, determines the number of grass-associated pathogens transferred to Compartment 8, MOWED GRASS, by TAU68 each week until the pathway ends.

Time of first transfer into compartment - 240 hours into the pathway.

Time of last transfer out of compartment - Transfers are made from this compartment daily. The time of the last transfer depends upon the user specified pathway duration.

Process function - RH06
Activated: 240 hours into the pathway.
Duration: Until the end of the pathway.
Rates: Salmonella: -0.096*N(6)/hour. (72, 73)
Ascaris: -1.54*N(6)/hour. (7, 78)
Poliovirus: -0.069*N(6)/hour. (49)

Transfers into compartment -
TAU56 (time = 240 hours) = FRPLNT*N(5), Transfer occurs 240 hours into the pathway.
TAU56 (time > 240 hours) = 0.1*FRPLNT*N(5), Transfer occurs at 24-hour intervals from 264 hours into the pathway.

Transfers out of compartment -
TAU64 = FREM*N(6), Transfer occurs at 24-hour intervals from 240 hours.
TAU65 = FRDRT*N(6), Transfer occurs at 24-hour intervals from 240 hours into the pathway.
TAU68 = PSTMG*N(6), Transfer occurs at weekly intervals from 840 hours into the pathway.

Compartment 7, PARTICULATES --

This compartment simulates the effects of a windstorm before the grass is up. Dust is blown from the SOIL SURFACE (TAU57); the amount can be specified by assigning a value to WTPAR7. The default value for this variable assumes that 15 milligrams of compost-amended soil is suspended in each cubic meter of air in a 10-meter high volume above the 0.05 hectare lawn. The storm occurs on the fifth day after compost application. Process functions for this compartment are delayed 12 hours. The rates of inactivation simulate rapid drying.

Time of first transfer into compartment - 120 hours into the pathway.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RH07
Activated: 132 hours into the pathway.
Duration: Until all pathogens are depleted or the pathway ends.

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Rates: Salmonella: -0.46*N(7)/hour. (8)
Ascaris: -0.25*N(7)/hour. (22, 40, 74)
Poliovirus: -0.38*N(7)/hour. (88, 97)

Transfers into compartment -
TAU57 = (WTPAR7/(FRTSUR*(APRATE - WTRES2 - WTPAR3)))*N(5),
Transfer occurs 120 hours into the pathway.

Transfers out of compartment - None.

Compartment 8, MOWED GRASS --

Five weeks after the lawn is seeded it is ready to be mowed. It is mowed once a week thereafter. Pathogens are transferred from Compartment 6, PLANT SURFACE, at each mowing. The variable PSTMG determines the fraction of the grass-associated pathogens removed with grass clipping. Pathogens transfer from this compartment to Compartment 4, DIRECT REMOVAL, after each mowing. The fraction transferred by TAU84 is controlled by GRAREM. This transfer simulates manual removal of grass clippings from the lawn area, an operation which involves hand contact with the grass. After 4 hours all clippings have been bagged or added to a compost pile and the population of this compartment is set to zero.

Time of first transfer into compartment - 840 hours into the pathway.

Time of the last transfer out of compartment - Transfers are made from this compartment weekly. The time of the last transfer depends upon the user-specified pathway duration.

Process function - RHO8
Activated: 844 hours and then at weekly intervals.
Duration: 1 hour.
Rates: Salmonella: -N(8)/hour after 4 hours.
Ascaris: -N(8)/hour after 4 hours.
Poliovirus: -N(8)/hour after 4 hours.

Transfers into compartment -
TAU68 = PSTMG*N(6), Transfer occurs at weekly intervals from 840 hours into the pathway.

Transfers out of compartment -
TAU84 = GRAREM*N(8), Transfer occurs at weekly intervals from 841 hours.

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JOB A

PATHWAY 10 - SLUDGE TREATMENT PATHWAY - LIQUID SLUDGE

General Considerations

This pathway describes the fate of sewage sludge pathogens during the treatment processes involved in the generation of liquid, raw or anaerobically digested sludge to be used as fertilizer. Figure 10 shows the process compartments and transfers which define this treatment option. The differential equations which describe this pathway, reflecting the relationships expressed in Figure 10 and forming the basis of the computer program, are presented in Table 10a. Each process function (ρ_i) and transfer function (τ_i) is defined in the following section, where each compartment is described in detail.

Table 10b lists both the definitions of and default values for the input variables used to define environmental factors which affect process and transfer functions. The model user may supply a value for any input variable and, thus, set the program to model a specific situation of concern. Table 10b also lists output variables generated by the computer program. These variables are not available to the user as input but are often used in pathway descriptions to define time increments and pathogen levels. The general considerations and assumptions discussed below were made to facilitate model development.

a. The pathway considers the total, 1-day sludge production of a 30-million gallon per day (MGD) sewage treatment plant. Only those processes concerned with the generation and processing of sewage sludge are considered. The following assumptions were made concerning the character of the raw sewage entering the treatment plant (84).

   1. Total solids concentration of the raw sewage is 225 mg/l. This represents a total plant capacity of 25,531 kilograms of dry solids per day.

   2. Primary sedimentation is 60 percent efficient in the removal of suspended solids. Hence, 15,318 kilograms of dry solids are present in the raw sludge entering the pathway. This represents 306 cubic meters of liquid sludge with a solids concentration of 5 percent.

b. The number of pathogens entering the pathway each day in the 30 million gallons of raw sewage is a model user-supplied value that may be based on personal experience. The user may supply either the total number of pathogens entering the pathway (variable ASCIN in Table 10b) or both the number of pathogens per kilogram of sludge (ASCRS) and the amount of raw sludge being considered (PLCAP). The default values that have been provided within the computer program represent "average" pathogen levels in municipal sewage (1, 4, 28, 32, 77), but user-supplied values based on local experience will provide the

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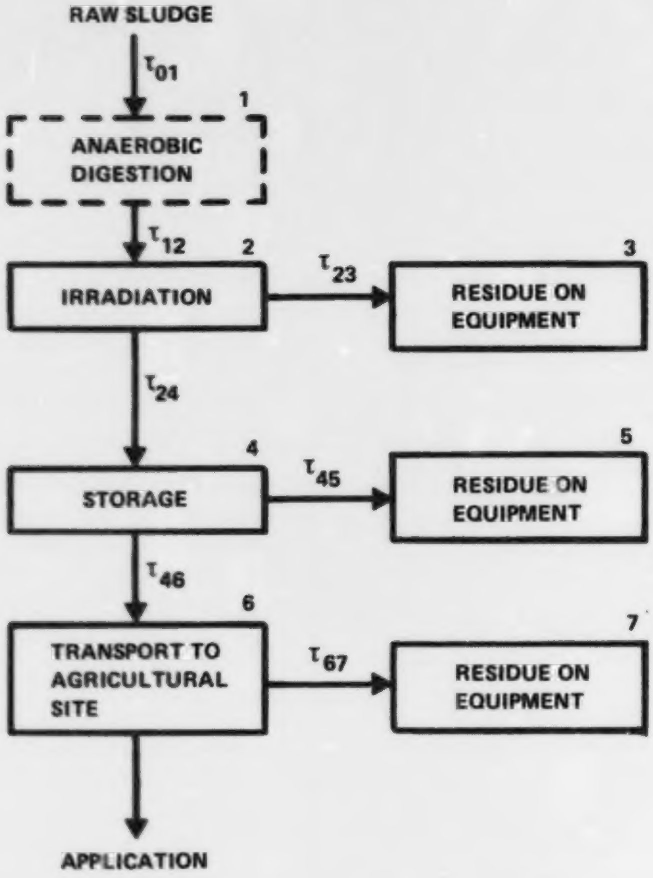
RAW SLUDGE
τ_{01}
1
ANAEROBIC DIGESTION
τ_{12}
2
IRRADIATION
τ_{23}
3
RESIDUE ON EQUIPMENT
τ_{24}
4
STORAGE
τ_{45}
5
RESIDUE ON EQUIPMENT
τ_{46}
6
TRANSPORT TO AGRICULTURAL SITE
τ_{67}
7
RESIDUE ON EQUIPMENT
APPLICATION

Figure 10. Sludge Treatment Pathway - Liquid Sludge

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TABLE 10a. DIFFERENTIAL EQUATIONS FOR PATHWAY 10
SLUDGE TREATMENT PATHWAY - LIQUID SLUDGE

$$\dot{N}_1 = \tau_{01} - \tau_{12} + \rho_1$$

$$\dot{N}_2 = \tau_{12} - \tau_{23} - \tau_{24} + \rho_2$$

$$\dot{N}_3 = \tau_{23} + \rho_3$$

$$\dot{N}_4 = \tau_{24} - \tau_{46} - \tau_{45} + \rho_4$$

$$\dot{N}_5 = \tau_{45} + \rho_5$$

$$\dot{N}_6 = \tau_{46} - \tau_{67} + \rho_6$$

$$\dot{N}_7 = \tau_{67} + \rho_7$$

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TABLE 10b. VARIABLES FOR PATHWAY 10
SLUDGE TREATMENT PATHWAY - LIQUID SLUDGE

POSITION	DEFAULT VALUE	VARIABLE	DEFINITION
			INPUT VARIABLES
1	1.3057E+7 4.5698E+2 5.2226E+7	ASCRS	Number of pathogens per kilogram of dry solids after primary sedimentation.
2	1.5318E+4	PLCAP	Plant capacity in kilograms per day of dry solids after primary sedimentation.
3	PLCAP*ASCRS	ASCIN	Number of pathogens per day entering pathway. If present, overrides first two variables
4	1.	ANAER	Selects Anaerobic Digestion Compartment if set = 1.0; does not select if set = -1.0.
5	720.	ANTIM	If Anaerobic Digestion Compartment is selected, then this sets the duration of the Compartment (in hours).
6	20.	TEMP	Ambient temperature throughout pathway in degrees Celsius.
7	150. 150. 1000.	DOSE	Radiation dosage in kilorads from irradiator.
8	5.	WTRES3	Dry weight in kilograms of sludge transferred to Residue in Compartment 3.
9	168.	TSTOR	Duration of Storage Compartment (in hours).
10	5.	WTRES5	Dry weight in kilograms of sludge transferred to Residue in Compartment 5.
11	2.	TPORT	Duration of Transport to Agricultural Site Compartment. (in hours)

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TABLE 10b. (concluded)

POSITION	DEFAULT VALUE	VARIABLES	DEFINITION
12	20.	WTRES7	Dry weight in kilograms of residue generated in Compartment 7.
		OUTPUT VARIABLES	
13	(output)	STIME1	Time at completion of Compartment 1.
14	(output)	STIME2	Time at completion of Compartment 2.
15	(output)	STIME3	Time at completion of Compartment 4.
16	(output)	STIME4	Time at completion of Compartment 6.
17	(output)	PTOTL	Pathogens per kilogram of dry solids at the end of the pathway.

NOTES: The number of pathogens per day entering the pathway will default to PLCAP*ASCRS if no value is specified for ASCIN. If a value is specified for ASCIN, it will override the PLCAP*ASCRS value.

Whenever three default values are specified for any variable in the list above, the order is salmonellae, ascaris, poliovirus pathogen types. The appropriate default value will be selected to agree with the pathogen type being considered in a particular run.

All units of measure are in kilograms, degrees Celsius, or hours unless otherwise stated.

Variables labeled "output" are for internal computations and are not available to the user as input.

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most useful model output. The user must select one pathogen type for each model run.

c. The anaerobic digestion process is optional, as is indicated by the dashed lines surrounding this compartment in Figure 10. To model raw, undigested sludge, this process is bypassed and the entering pathogen population is transferred directly to the next pathway process, which is irradiation. The model assumes a batch, mesophilic, anaerobic digestion process. Duration of digestion is a user-supplied value which defaults to 30 days.

d. Sludge-associated pathogens are subjected to a user-specified dose of gamma irradiation. Default dosages provided in the model will give a three-log reduction in the total number of pathogens. The time required for the irradiation process depends on the dose desired and the amount of sludge to be processed. The time required to deliver the selected irradiation dose is based on the design of the Sandia Laboratories' Irradiator for Dried Sewage Solids, a prototype irradiator that can deliver a 1-megarad dose to 7000 kilograms (8 tons) of sludge in 1 day (61).

e. Storage of liquid sludge at the treatment facility is provided in the model. Storage units are assumed to hold 1 day's output. The default value for storage (specified by the variable TSTOR) is 7 days but the user may supply a time which reflects actual storage needs for a particular climate.

f. No airborne particulates are produced during liquid sludge treatment. The entire operation is assumed to be enclosed with the sludge being pumped through pipes from one process to the next.

g. The ambient temperature during the pathway is provided by the model user and remains constant throughout the pathway. A default temperature of 20°C is provided.

h. The transfer of pathogens with residue, at various locations, is computed by dividing the weight of the residue left by the total weight of sludge present in the transferring compartment and then multiplying this fraction by the number of pathogens present. The default values provided in the model are only estimates, and a fraction of transfer based on user experience would enhance the pathogen estimates in this and similar cases. All weights used in transfers are calculated on a dry weight basis.

i. The transport of liquid sludge to an application site is accomplished with the use of tanker trucks. The default value given for the time required for transport (TPORT) assumes that each truck holds 25,000 liters of liquid sludge.

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j. The total pathway duration is variable and depends on the model-user-selected values for the time of anaerobic digestion, the total dose of irradiation to be delivered, and the time selected for storage and transportation of the treated sludge.

Compartment Descriptions

Compartment 1, ANAEROBIC DIGESTION --

This treatment process is optional. The process functions of Compartment 1 will be activated only if the variable ANAER is set equal to one. This is the default condition. If any other value is assigned to the variable, the pathogen population will be transferred unaltered to Compartment 2. When ANAER = 1, the variable ANTIM, which specifies the digestion time, must be set to at least 24 hours because pathogens are transferred into the compartment over a 24-hour period.

Significant calculations - Review of the literature showed that populations of salmonella and poliovirus are reduced by approximately two and three orders-of-magnitude, respectively, during anaerobic digestion. This reduction is reported, regardless of the duration of the digestion period. Apparently, most of the reduction occurs over a relatively short period early in digestion and then the rate of reduction levels off. To simulate the net effect of anaerobic digestion, the process function RHO1 has been set to allow for a uniform reduction in population over the duration of digestion (ANTIM). If the anaerobic digestion time is less than 3.2 (for poliovirus) or 4.4 (for salmonella) the reduction in population occurs at the most rapid rate over the selected period of digestion. Because ascaris ova are not affected by anaerobic digestion, no change in ascaris occurs in the compartment.

The inactivation rate of pathogens during longer periods of anaerobic digestion is calculated by the model based on the pathogen type and the time selected for anaerobic digestion.

The equation describing the number of pathogens present at any point in time in the Anaerobic Digestion Compartment is:

$$N_t = N_0 e^{mt} \tag{1}$$

where N_t = the number of pathogens present at the beginning of the time increment under consideration.
N_0 = number of pathogens at the beginning of the anaeobic digestion process.
e = base of natural logarithm
t = elapsed time
m = inactivation rate constant

At a time 24 hours (t = 24) after the start of the pathway, all of the pathogens will have been transferred into the compartment and

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$$N_{24} = N_0e^{m*24} \tag{2}$$

For salmonella where a two-log reduction occurs over the period of anaerobic digestion, the number present at the end of anaerobic digestion is given by:

$$N_{ANTIM} = N_{24}\,(10^{-2}) = N_0e^{m*ANTIM} \tag{3}$$

Dividing equation 2 by equation 3 gives

$$10^2 = e^{m(24\ -\ ANTIM)} \tag{4}$$

Thus, $m = -\ln(10^2)/(ANTIM - 24)$

For this salmonella population undergoing anaerobic digestion, RH01 = m*N where N is the population at the beginning of the time increment being considered.

For poliovirus, the calculation is the same except that a three-log reduction is used.

Time of first transfer into compartment - Start of pathway.

Time of last transfer out of compartment - ANTIM.

Process function - RH01
    Activated: Start of pathway.
    Duration: Until ANTIM.
    Rates: Salmonella: -0.044*N(1)/hour, when ANTIM $\leq$ 4.4 days. (57, 77)
        (-ln(10.E2.)/(ANTIM - 24) *N(1)/hour, when ANTIM > 4.4 days.
    Ascaris: -0.00041*N(1)/hour. (22, 31, 32, 70)
    Poliovirus: -0.09*N(1)/hour, when ANTIM $\leq$ 3.2 days. (2, 59, 86)
        (-ln(10.E3)/(ANTIM - 24.))*N(1)/hour, when ANTIM > 3.2 days.

Transfers into compartment -
    TAU01 = ASCIN, Transfer occurs at the start of the pathway.

Transfers out of compartment -
    TAU12 = N(1), Transfer occurs at ANTIM.

Compartment 2, IRRADIATION --

This compartment describes the change in pathogen populations when sludge is subjected to gamma irradiation with cesium-137. The radiation

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dose to be delivered to the sludge is a variable (DOSE). The time required to deliver the selected dose to the sludge is calculated by the model using the processing capacity of the Sandia Irradiator for Dried Sewage Solids which can deliver a 1,000-krd dose to 8 tons (7272 kg) of sludge in a 24-hour period. The relationship between delivered dose and processing capacity is inversely proportional (i.e., at the lower dose of 500 krd, 16 tons (14,544 kg) can be processed per day). For example, if 20,000 kilograms of sludge is to be given a radiation dose of 150 krd, 0.4125 days, as is shown in the equation, would be required to process the sludge.

$$20000 \text{ kg} \div \left(\frac{1000 \text{ krd}}{150 \text{ krd}} \times 7272 \frac{\text{kg}}{\text{day}}\right) = 0.4125 \text{ days}$$

Responses of pathogens to irradiation, as interpreted in process function rates, assume that a fraction or multiple of the D_{10} value dose will result in the corresponding fraction or multiple pathogen reduction. The D_{10} value for salmonella is 54 krds. Therefore, a dose of 135 krd would result in a 2.5 order-of-magnitude reduction in the salmonella population. Once the total level of pathogen reduction has been determined as just described, the model distributes the reduction evenly over the time specified for sludge processing. The D_{10} values used in the model are: salmonella - 54 krd (8, 94), ascaris - 50 krd (7, 9), and poliovirus - 150 krd (85).

Two components are included in the process function for this compartment. RH21 models the effects of irradiation while RH22 models the effects of heat.

Sludge and associated pathogens are transferred from the IRRADIATION compartment to Compartment 3, RESIDUE ON EQUIPMENT, by TAU23, and Compartment 4, STORAGE, by TAU24. At STIME2 the transfer from IRRADIATION to Compartment 3 is made. This transfer represents a residue of sludge left on the irradiator. The bulk of the sludge is transferred to Compartment 4. This compartment represents the storage of sludge after irradiation.

> Significant calculations - RH21, the process function describing inactivation of pathogens by gamma radiation is determined using the following considerations.
>
> The first transfer into the compartment occurs at STIME1, and the last transfer out of the compartment occurs at STIME2, which is the sum of STIME1 and the irradiation processing time calculated as described above. During this period, a pathogen population is reduced by a factor of $10^{(DOSE/D_{10})}$.
>
> The equation describing the number of pathogens present at any given time during the irradiation process is:

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$$N = N_0 e^{mt} \qquad (1)$$

where N = number of pathogens present at the beginning of the time increment under consideration
N_0 = number of pathogens at the beginning of the irradiation process
e = base of natural logarithms
t = elapsed time
m = inactivation rate constant

Then at STIME1,

$$N_{STIME1} = Ne^{(m*STIME1)} \qquad (2)$$

and at STIME2,

$$N_{STIME2} = N_{STIME1} \; 10^{(-DOSE/D_{10})} \qquad (3)$$

Dividing equation 2 by equation 3 gives

$$10^{(DOSE/D_{10})} = e^{(m(STIME1 - STIME2)} \qquad (4)$$

Thus,

$$m = (-\ln(10^{(DOSE/D_{10})}))/(STIME2 - STIME1)$$

For this population undergoing irradiation, RH21 = m*N where N is the population at the beginning of the time increment being considered.

Time of first transfer into compartment - STIME1.

Time of last transfer out of compartment - STIME2.

Process function - RHO2
Activated: STIME1.
Duration: Until STIME2.
Rates: RHO2 = RH21 + RH22
Salmonella: RH21 = ((ln(10.E(DOSE/5.4)))/(STIME2 -STIME1))*N(2)/hour. (8, 94)
RH22 = -0.05*N(2)/hour, for TEMP < 40. (8, 93)
= -3.45*N(2)/hour, for TEMP ≥ 40. (8, 93)
Ascaris: RH21 = ((ln(10.E(DOSE/50.)))/(STIME2 -STIME1))*N(2)/hour. (7, 9)
RH22 = 0.0*N(2)/hour, for TEMP < 40 (7, 9, 38)

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= -1.5*N(2)/hour, for TEMP ≥ 40 (7, 78)

Poliovirus: RH21 = ((-ln(10.E(DOSE/150.)))/(STIME2 -STIME1) *N(2)/hour. (85)

RH22 = -0.38*N(2)/hour, for TEMP ≥ 45. (88, 97)

= -0.01*N(2)/hour, for TEMP < 45. (87)

Transfers into compartment -
TAU12 = N(1), Transfer occurs at STIME1.

Transfers out of compartment -
TAU23 = (WTRES/PLCAP)*N(2), Transfer occurs at STIME2.
TAU24 = N(2) -TAU23, Transfer occurs at STIME2.

Compartment 3, RESIDUE ON EQUIPMENT --

Some sludge and associated pathogens are assumed to remain on the irradiation equipment after the treated sludge has been removed from the area. The user may supply the weight of sludge left behind by specifying a value for variable WTRES3. There are three compartments described by the title RESIDUE ON EQUIPMENT in this pathway: Compartment 3, Compartment 5, and Compartment 7. To avoid confusion in this and other pathways a naming system was used in which the "weight transferred to RESIDUE" is abbreviated "WTRES" and the number of the compartment is appended. WTPAR3 is the weight of sludge transferred to RESIDUE ON EQUIPMENT in Compartment 3. The calculation to determine the fraction of input pathogens associated with this weight of sludge is completed before the transfer into this compartment from Compartment 2.

Time of first transfer into compartment - STIME2.

Time of last transfer out of the compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RHO3
Activated: STIME2 + 24 hours.
Duration: 1 hour.
Rates: Salmonella: -N(3)/hour.
Ascaris: -N(3)/hour.
Poliovirus: -N(3)/hour.

Transfers into compartment -
TAU23 = (WTRES3/PLCAP)*N(2), Transfer occurs at STIME2.

Transfers out of compartment - None.

Compartment 4, STORAGE --

Liquid sludge cannot be applied to agricultural sites when the ground is frozen or saturated. It is assumed that adequate storage space is

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available at the treatment plant. Pathogens transfer into this compartment at the end of IRRADIATION, at STIME2. The user sets the time of STORAGE by specifying the value of TSTOR. At the end of STORAGE an amount of sludge will be left on the sides of the storage unit. The user specifies the dry weight of this RESIDUE in the variable WTRES5. The bulk of the sludge and sludge-associated pathogens are transferred by TAU46 to Compartment 6, TRANSPORT to AGRICULTURAL SITE.

Time of first transfer into compartment - STIME2.

Time of last transfer out of compartment - STIME3.

Process function - RHO4
Activated: STIME3.
Duration: TSTOR.
Rates: Salmonella: 0.13*N(4)/hour, for 20 < TEMP < 45 to an upper limit of 1x10^9 salmonella per kilogram of sludge solids. (76)
-3.45*N (4)/hour, for TEMP ≥ 45.(8, 93)
0.0*N(4)/hour, for TEMP < 20.
Ascaris: 0.00041*N(4)/hour, for 20 < TEMP < 40. (22, 31, 32, 70)
-1.535*N(4)/hour, for TEMP ≥ 40. (7, 78)
0.0*N(4)/hour, for TEMP ≤ 20.
Poliovirus: 0.0.*N(4)/hour, for TEMP < 45. (44, 87)
-0.38*N(4)/hour, for TEMP ≥ 45. (88, 97)

6-1/2"
9-1/8"

Transfers into compartment -
TAU24 = N(2) - TAU23, Transfer occurs at STIME2.

Transfers out of compartment -
TAU45 = (WTRES5/PLCAP)*N(4), Transfer occurs at STIME3.
TAU46 = N(4) - TAU45, Transfer occurs at STIME3.

Compartment 5, RESIDUE ON EQUIPMENT --

A portion of the sludge slurry will remain on the walls of the storage unit following removal of sludge to the transporting tankers. This thin layer is assumed to dry in a manner similar to sludge in a drying bed or at 0.7 times the clear water evaportion rate for the area (after removal of free water which would drain to the floor of the storage unit). The clear water evaporation rate used in the model is 2.1 m/yr (10, 84). The user may supply the weight of sludge left behind by specifying a value for WTRES5.

Significant calculations - The percent solids concentration of the drying sludge is calculated dynamically as a linear function.

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Time of drying in days =

$$\frac{83.25 - (100 - \%\ \text{solids})}{1.35}\text{, for \% solids} > 20.$$

$$\frac{95.0 - (100 - \%\ \text{solids})}{7.25}\text{, for \% solids} \leq 20.$$

Time of first transfer into compartment - STIME2.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RHO5
Activated: STIME2.
Duration: Until STIME3.
Rates:
Salmonella: 0.13*N(5)/hour, for PRSOL ≤ 70 and 20 ≤ TEMP < 40. There is an upper limit placed on growth of 1×10^9 salmonella per kilogram dry solids. The growth of salmonella in sludge at less than 80 percent solids is an estimate based upon one-half the growth rate of E.coli in sterile sludge (76).
-0.05*N(5)/hour, for 70 < PRSOL < 80 and TEMP < 40. (8)
-3.45*N(5)/hour, for PRSOL < 80 and TEMP > 40. (8, 93)
-0.46*N(5)/hour, for PRSOL ≥ 80 and any temperature. (8)
0.0*N(5)/hour, for PRSOL < 80 and TEMP ≤ 20.
Ascaris: -0.0012*N(5)/hour, for PRSOL < 95 and TEMP < 40. (7, 9, 38)
-1.535*N(5)/hour, for 40 ≤ TEMP ≤ 50 and PRSOL < 95. (7, 78)
-0.25*N(5)/hour, for PRSOL ≥ 95. (22, 40, 74)
Poliovirus: -0.01*N(5)/hour, for PRSOL < 65 and TEMP < 45. (44, 87)
-0.38*N(5)/hour, for TEMP ≥ 45. (88, 97)
-0.02*N(5)/hour, for PRSOL ≥ 65 and TEMP < 45. (87)

Transfers into compartment -
TAU45 = (WTRES5/PLCAP)*N(4), Transfer occurs at STIME3.

Transfers out of compartment - None

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Compartment 6, TRANSPORT TO AGRICULTURAL SITE --

After sludge is irradiated it must be delivered to the site where it will be used. It is possible that the sludge will be stored either near the treatment plant or near the agricultural site before being utilized. This compartment provides the process functions for stored sludge. Sludge in transit is, in effect, stored since the factors affecting pathogen survival are temperature and dryness in both cases. The user may specify the duration of the activities in this compartment by assigning a value to TPORT.

A weight of sludge and associated pathogens is transferred to Compartment 7 by TAU67 at STIME4. STIME4 equals STIME3, the time at completion of Compartment 4, plus TPORT, the duration of Compartment 6. This transfer simulates a residue left in a storage facility and on equipment when sludge is utilized at an agricultural site.

Time of first transfer into compartment - STIME3.

Time of last transfer out of compartment -STIME4.

6-1/2"

Process function - RHO6
Activated: STIME3.
Duration: TPORT.
Rates: Salmonella: 0.13*N(6)/hour, for $20 < TEMP < 45$. There is an upper limit placed on growth of $1x10^9$ salmonella per kilogram dry solids. The growth of salmonella in sludge at less than 80 percent solids is an estimate based upon one-half the growth rate of E.coli in sterile sludge (76).
-3.45*N(6)/hour, for $TEMP \geq 45$. (8, 93)
0.0*N(6)/hour, for $TEMP \leq 20$.
Ascaris: 0.0*N(6)/hour, for ≤ 20. (7, 9, 38)
-0.00041*N(6), for $20 < TEMP < 40$. (22, 31, 32, 70)
-1.535*N(6)/hour, for $TEMP \geq 40$. (7, 78)
Poliovirus: -0.01*N(6)/hour, for $TEMP < 45$. (44, 87)
-0.38*N(6)/hour, for $TEMP \geq 45$. (88, 97)

9-1/8"

Transfers into compartment -
TAU46 = N(4) - TAU45, Transfer occurs at STIME3.

Transfers out of compartment -
TAU67 = (WTRES7/PLCAP)*N(6), Transfer occurs at STIME4.

Compartment 7, RESIDUE ON EQUIPMENT --

After liquid sludge is delivered to an application site, a residue will remain in the delivery trucks. This thin layer is assumed to dry in

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a manner similar to sludge in a drying bed. To show the effects of drying, the pathway continues for 24 hours after sludge delivery. The user may supply the weight of sludge left behind by specifying a value for WTRES7.

Time of first transfer into compartment - STIME4.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RHO7
Activated: STIME4
Duration: 24 hours.
Rates:

Salmonella:
- 0.13*N(7)/hour, for % solids of sludge < 70 and 20 < TEMP ≤ 40 to an upper limit of 1×10^9 per kilogram solids. This growth rate is 1/2 the rate of _E.coli_ in sterile sludge. (76)
- -0.05*N(7)/hour, for 70 < % solids < 80 and TEMP < 40. (8)
- -3.45*N(7)/hour, for % solids < 80 and TEMP > 40. (8, 93)
- -0.46*N(7)/hour, for % solids ≥ 80. (8)
- 0.0*N(7)/hour, for % solids < 80 and TEMP < 20.

Ascaris:
- -0.0012*N(7)/hour, for TEMP < 40 and % solids < 95. (40)
- -1.535*N(7)/hour, for 40 < TEMP ≤ 50 and % solids < 95. (7, 78)
- -0.25*N(7)/hour, for % solids ≥ 95. (22, 40, 74)

Poliovirus:
- -0.01*N(7)/hour, for % solids < 65 and TEMP < 45. (44, 87)
- -0.38*N(7)/hour, for TEMP ≥ 45. (88, 97)
- -0.02*N(7)/hour, for % solids ≥ 65 and TEMP < 45. (87)

Transfers into compartment -
TAU67 = (WTRES7/PLCAP)*N(6), Transfer occurs at STIME4.

Transfers out of compartment - None.

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PATHWAY 11 - SLUDGE APPLICATION PATHWAY - LIQUID SLUDGE USED AS FERTILIZER FOR CROPS DESTINED FOR HUMAN CONSUMPTION

General Considerations

This pathway describes the fate of sewage sludge pathogens after the application of liquid, raw or anaerobically digested sludge to a 1-hectare field which will be planted in vegetable crops destined for human consumption. Figure 11 shows the process compartments and transfers which define this application regime. The differential equations which describe this pathway are presented in Table 11a. Each process function (ρ_i) and transfer function (τ_i) is defined in the following section, where each compartment is described in detail.

Table 11b lists the definitions of and default values for the input variables used to define environmental factors which affect process and transfer functions. The model user may supply a value for any input variable and, thus, set the program to model a specific situation of concern. Table 11b also lists output variables generated by the computer program. These variables are not available to the user as input but are often used in pathway descriptions to define time increments and pathogen levels. The general considerations and assumptions discussed below were made to facilitate model development.

a. The duration of the pathway is determined by the user. The pathway terminates after crops are harvested, and the user may specify growth periods appropriate to ripen a chosen crop. The default pathway duration of 1680 hours (70 days) is an average value when the three vegetables used as examples are grown under adequate irrigation in the sunny Southwest (18, 67). Varying pathway duration by changing the value of THARV will simulate other climates.

b. The ambient temperature of the environment is specified for each run of the model by the variable TEMP and remains constant throughout. The default ambient temperature is 20°C.

c. The amount of sludge applied to the field (APRATE) and the concentration of pathogens in that sludge (ASCRS) are user-specifiable variables. The model allows one application of sewage sludge fertilizer by one of three methods; injection 20 cm under the surface, spray irrigation, or spread/flow irrigation. The sludge is incorporated into the soil before crops are seeded. There are no additional applications of sludge prior to harvest. However, the user may specify a concentration of pathogens in irrigation water. Careful manipulation of this variable can simulate repeated flow irrigation with liquid sludge. Default values are based on adding a moderate amount of sludge (48), approximately 34 metric tons/hectare, to the field. The default application rate assumes the sludge being applied is five percent solids. The default values for the number of pathogens present in the sludge reflect a conservative "worst

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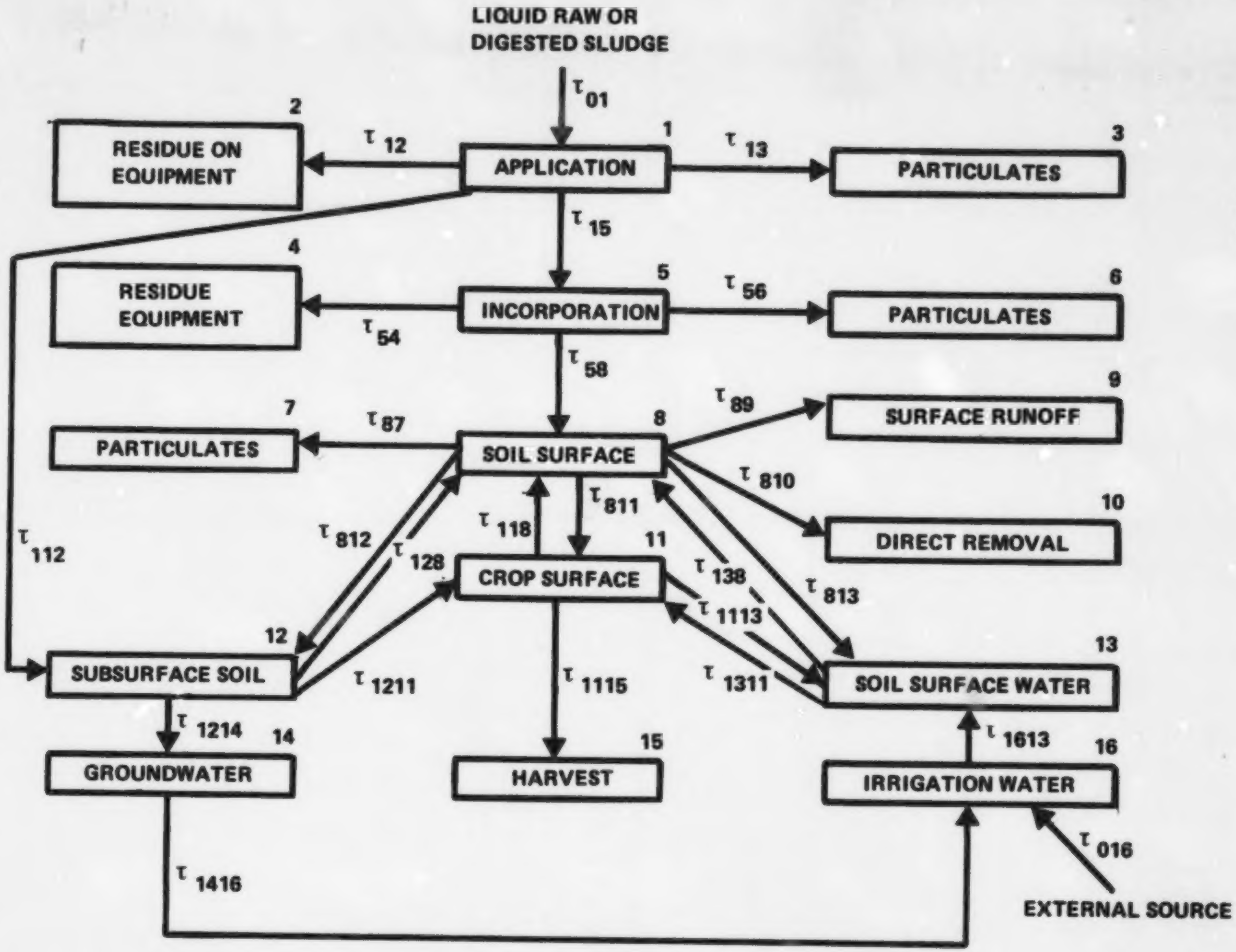
LIQUID RAW OR DIGESTED SLUDGE
τ_{01}
1 APPLICATION
2 RESIDUE ON EQUIPMENT
3 PARTICULATES
4 RESIDUE EQUIPMENT
5 INCORPORATION
6 PARTICULATES
7 PARTICULATES
8 SOIL SURFACE
9 SURFACE RUNOFF
10 DIRECT REMOVAL
11 CROP SURFACE
12 SUBSURFACE SOIL
13 SOIL SURFACE WATER
14 GROUNDWATER
15 HARVEST
16 IRRIGATION WATER
EXTERNAL SOURCE
τ_{12}
τ_{13}
τ_{15}
τ_{54}
τ_{56}
τ_{58}
τ_{87}
τ_{89}
τ_{810}
τ_{811}
τ_{118}
τ_{812}
τ_{128}
τ_{112}
τ_{138}
τ_{1113}
τ_{813}
τ_{1211}
τ_{1311}
τ_{1115}
τ_{1214}
τ_{1613}
τ_{016}
τ_{1416}

Figure 11. Sludge Application Pathway - Liquid Sludge Used as a Fertilizer for Crops Destined for Human Consumption

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TABLE 11a. DIFFERENTIAL EQUATIONS FOR PATHWAY 11

SLUDGE APPLICATION PATHWAY - LIQUID SLUDGE USED AS A FERTILIZER FOR CROPS DESTINED FOR HUMAN CONSUMPTION

$$\dot{N}_1 = \tau_{01} - \tau_{12} - \tau_{13} - \tau_{15} - \tau_{112} + \rho_1$$

$$\dot{N}_2 = \tau_{12} + \rho_2$$

$$\dot{N}_3 = \tau_{13} + \rho_3$$

$$\dot{N}_4 = \tau_{54} + \rho_4$$

$$\dot{N}_5 = \tau_{15} - \tau_{54} - \tau_{56} - \tau_{58} + \rho_5$$

$$\dot{N}_6 = \tau_{56} + \rho_6$$

$$\dot{N}_7 = \tau_{87} + \rho_7$$

$$\dot{N}_8 = \tau_{58} + \tau_{118} + \tau_{128} + \tau_{138} - \tau_{78} - \tau_{89} - \tau_{810} - \tau_{811} - \tau_{812} - \tau_{813} + \rho_8$$

$$\dot{N}_9 = \tau_{89} + \rho_9$$

$$\dot{N}_{10} = \tau_{810} + \rho_{10}$$

$$\dot{N}_{11} = \tau_{811} + \tau_{1211} + \tau_{1311} - \tau_{1113} - \tau_{1115} + \rho_{11}$$

$$\dot{N}_{12} = \tau_{112} + \tau_{812} - \tau_{128} - \tau_{1211} - \tau_{1214} + \rho_{12}$$

$$\dot{N}_{13} = \tau_{813} + \tau_{1113} + \tau_{1613} - \tau_{138} - \tau_{1311} + \rho_{13}$$

$$\dot{N}_{14} = \tau_{1214} - \tau_{1416} + \rho_{14}$$

$$\dot{N}_{15} = \tau_{1115} + \rho_{15}$$

$$\dot{N}_{16} = \tau_{016} + \tau_{1416} - \tau_{1613} + \rho_{16}$$

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TABLE 11b. VARIABLES FOR PATHWAY 11

SLUDGE APPLICATION PATHWAY - LIQUID SLUDGE USED AS A FERTILIZER FOR CROPS DESTINED FOR HUMAN CONSUMPTION

POSITION	DEFAULT VALUE	VARIABLE	DESCRIPTION
		INPUT VARIABLES	
1	1.95E+07 4.95E+02 6.52E+07	ASCRS	Number of pathogens per kilogram of applied sludge.
2	3.5E+04	APRATE	Application rate of sludge in kilograms per hectare.
3	ASCRS*APRATE	ASCIN	Total number of pathogens entering pathway. If present, overrides first two variables.
4	20.	TEMP	Ambient temperature throughout pathway in degrees Celsius.
5	+1.	CROP	Type of crop being grown: +1. = Above-ground 0. = On-ground -1. = Below-ground.
6	+1.	APMETH	Method of applying sludge: +1. = Spread/flow 0. = Injection -1. = Spray.
7	1848.	THARV	Time of harvest in hours.
8	-2.	TRAIN	Time in hours of arbitrary rain. (If -2., there is no rain.)
9	0.0085 0.0005 0.0085	FRRAIN	Fraction of total pathogens transferred from Soil Surface to Surface Runoff by rain.
10	1368.	TWIND	Time in hours of arbitrary windstorm. Values between 57 days and THARV are permissable. (If -2., there is no windstorm.)

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TABLE 11b. (continued)

POSITION	DEFAULT VALUE	VARIABLES	DEFINITION
11	6.0	DEPTH	Depth of irrigation water in centimeters.
12	1.0E-6	DILGRN	Groundwater and use dilution.
13	0.5	DILIRR	Fraction of irrigation water from Groundwater.
14	0.0	COUNT	External Source pathogen input into irrigation water (total-population).
15	10.	WTRES2	Dry weight of sludge in kilograms left as a residue on equipment used for Application.
16	5.	WPAR3A	Dry weight of particulates in kilograms generated by sludge Application for APMETH = -1.
17	0.0	WPAR3B	Dry weight of particulates in kilograms generated by sludge Application for APMETH = +1. or 0.0.
18	1.	FSSURA	Fraction of ASCIN transferred to Subsurface Soil during sludge Application when APMETH = 0.0.
19	0.0	FSSURB	Fraction of ASCIN transferred to Subsurface Soil during sludge Application when APMETH = +1. or -1.
20	0.0	WRES4A	Dry weight of sludge in kilograms left as a residue on equipment used during Incorporation when APMETH = 0.0.
21	5.	WRES4B	Dry weight of sludge in kilograms left as a residue on equipment used during Incorporation when APMETH = +1. or -1.

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TABLE 11b. (continued)

POSITION	DEFAULT VALUE	VARIABLE	DEFINITION
22	5.	WTPAR6	Dry weight of particulates in kilograms generated by Incorporation.
23	15.	WTPAR7	Dry weight of particulates in kilograms generated from Soil Surface during windstorm.
24	0.0125	WTDRM	Weight of transfer from Soil Surface to Direct Removal before THARV.
25	0.05	WTDRMH	Weight of transfer from Soil Surface to Direct Removal at THARV.
26	0.05 0.01 0.05	SUSPND	Fraction of Soil Surface associated pathogens suspended in Soil Surface Water.
27	1.19E-08	FCROP1	Fraction of transfer from Soil Surface to above-ground Crop Surface.
28	0.06	FCROP2	Fraction of transfer from Soil Surface to below-ground Crop Surface.
29	9.66E-04	FCROP3	Fraction of transfer from Soil Surface to below-gound Crop Surface.
30	0.001 0.0 0.93	SUBSOL	Fraction of transfer from Soil Surface to Subsurface Soil.
31	1.93E-04	FSSCRP	Fraction of transfer from Subsurface Soil to below-ground Crop Surface.
32	2.	FILTR8	Infiltration rate of Soil Surface Water (cm/hr).

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TABLE 11b. (concluded)

POSITION	DEFAULT VALUE	VARIABLE	DEFINITION
33	0.0001	FSUR1	Fraction of transfer from Soil Surface Water to above-ground Crop Surface.
34	0.012	FSUR2	Fraction of transfer from Soil Surface Water to on-ground Crop Surface.
35	0.0	FSUR3	Fraction of transfer from Soil Surface Water to below-ground Crop Surface.
36	0.0	FRSUR	Fraction of transfer from Subsurface Soil to Soil Surface. A positive value indicates cultivation or another specific soil disturbance.
37	0.0	FRGRND	Fraction of transfer from Subsurface Soil to Groundwater.
		OUTPUT VARIABLES	
38	(output)	FPCU	Final pathogen count per crop unit.
39	(output)	TIRRG	Time of irrigation.

NOTES: The number of pathogens per day entering the pathway will default to APRATE*ASCRS if no value is specified for ASCIN. If a value is specified for ASCIN, it will override the APRATE*ASCRS value.

Whenever three default values are specified for any variable in the list above, the order is salmonellae, ascaris, poliovirus pathogen types. The appropriate default value will be selected to agree with the pathogen type being considered in a particular run.

All units of measure are in kilograms, degrees Celsius, or hours unless otherwise stated.

Variables labeled "output" are for internal computations and are not available to the user as input.

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case" and are set equal to the concentration of each pathogen in raw sludge from a municipal treatment system (1, 4, 28, 32, 77). The value of output variable PTOTL, position 17 of Pathway 10's P-array, is equal to the number of pathogens per kilogram of sludge (dry weight) at the end of a run of Pathway 10. The user may run Pathway 10 for one of the three pathogens and then use the output value of PTOTL as the value for ASCRS, the variable in position 1 of Pathway 11's P-array. ASCRS determines the number of pathogens per kilogram of sludge applied to the field as fertilizer. In this way, Pathways 10 and 11 may be linked and a selected pathogen followed through treatment and application of liquid sludge.

d. The area of the field is set at 1 hectare. This area was used in determining plant spacing, leaf surface exposures, crop yields, etc.

e. The pathway is defined for three types of crops:
Above-Ground -- vegetables which ripen on bushy plants above the ground and which do not directly contact either the soil surface or irrigation water during growth. Hybrid tomatoes were used as the example. Fifty-four rows of tomatoes, spaced 1.5 meters apart with plants on 0.5-meter centers within each row, fit in the field and will produce 2.2 kilograms of tomatoes per meter of row (34). Tomatoes were modeled as perfect spheres 10 centimeters in diameter and weighing 0.2 kilogram each (15).

On-Ground -- vegetables which grow on spreading vines or runners and which lay directly on the ground during most of their growing period. These vegetables are in direct contact with the surface soil and may be covered by irrigation water if the depth of irrigation exceeds the size of the vegetable. Zucchini squash was used as the example. Spacing for the crop is 1 meter between rows and 0.5 meter between plants within the rows, so that there are 200 plants per 1000 meters of row (15, 34). Each plant will produce two squash which were modeled as perfect cylinders 20 centimeters long by 5 centimeters in diameter and weighing 0.2 kilogram. One-half the area of each squash is assumed to rest directly on the soil surface.

Below-ground -- root and tuber vegetables which develop completely underground. Carrots were used as the example of below-ground crops. The 1-hectare field will allow 200 rows of carrots spaced 0.5 meter apart with 0.1 meter between thinned plants (15, 34). Carrots are assumed to be perfect cylinders 20 centimeters long by 2.5 centimeters in diameter and weighing 0.1 kilogram. Because of their length, one-half of each carrot extends into the subsurface soil.

The user must select one crop type for each run of the pathway by specifying the value of CROP. The default value of +1. selects the above-ground crop type.

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f. During incorporation, sludge is disked into the soil - an operation which creates two distinct soil layers. The upper 10 centimeters of soil are a homogeneous mixture of sludge and soil. This zone is affected by changing temperatures and dries after each irrigation. The next 50 centimeters is the subsurface soil layer. This zone has a constant temperature and moisture level. Pathogens enter this zone with percolating water or during sludge application by the injection method. Because injection places sludge 20 centimeters (8 inches) below the soil surface, pathogens are distributed in the subsurface soil at application when the injection option is chosen. Transfers of pathogens from both soil layers to crop surfaces are under some constraints discussed below.

g. Pathogens in the surface soil are transferred to above-ground crops once during the crop cycle if a wind storm is included in the pathway. This windstorm, timed by default variable values to occur 60 days after planting, stirs up dust in a 10-meter high volume above the field. A fraction of this dust, in proportion to the volume of tomatoes relative to the total volume above the field, settles on tomatoes. As with particulates throughout all model pathways, the dust is assumed to be at a concentration of 15 mg/m^3 (82). Pathogens in the dust on above-ground crop surfaces will die off at a constant rate until crop harvest, and a fraction of the dust will fall from the vegetables and return to the soil surface. Pathogens from subsurface soil will not contact above-ground crops.

On-ground crops are in constant contact with surface soil and are considered to be at equilibrium with the soil, transferring as many pathogens to soil as are transferred from the soil, until harvest when a percentage of the total pathogen content of the surface soil layer is transferred to the crop. That percentage is based on a ratio of crop area in contact with the soil to the area of the field. All crops are assumed to be nonexistent until day 50 and from then on to be full size at harvest regardless of the harvest time selected. Pathogens in the subsurface soil do not contact on-ground crops.

Crops growing below ground are part of the soil until harvest when a fraction of both surface and subsurface soil pathogens are transferred to the crop. The ratio of the volume of the crop in each soil layer to the total volume of each layer determines the number of pathogens transferred.

h. Default values for soil factors describe a sandy loam soil. The water infiltration rate (26, 33) and water holding capacity of the soil (80) are functions of soil type and determine the duration of the soil surface water compartment. Values used in the transfer of pathogens from the surface to subsurface soil zones were based on the ability of sandy loam soils to filter

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and adsorb particles of different sizes carrying different charges. Variables are provided in the model for soil factors and the fractions of transfer between pathway compartments. The user may specify values for these variables which describe other soil types.

i. The field is irrigated initially by sludge application and with irrigation water every 7 days thereafter. During spray and spread/flow application of liquid sludge and during periodic irrigation the field is flooded to a uniform depth. The water then infiltrates the soil at a constant and uniform rate. Injected sludge will infiltrate the soil below injection depth as if the soil was uniformly flooded at that depth. The default depth of irrigation (DEPTH) is calculated to allow infiltration of water 60 centimeters below the surface (6), precluding transfer of pathogens to groundwater, while saturating the root zone of most vegetable crops. The default depth of sludge application neccessary to add 15 tons of dry solids to the field is 6.6 centimeters (assuming 5 percent solids sludge). Three-tenths centimeter would be solids and the 3-centimeter additional infiltration capacity (from the remaining 0.3 centimeter of water) is negligible with respect to groundwater contamination.

Injected sludge would percolate to 80 centimeters below the surface. A transfer to groundwater is more likely in this case but none have been reported in the literature. For this reason, the default value of FRGRND (the variable which specifies what fraction of subsurface soil pathogens will transfer to groundwater) is zero. The user may specify a positive value for FRGRND to simulate contamination of groundwater by either injected sludge or deep irrigation.

During each irrigation, infiltrating water will saturate the soil as it percolates downward until the trailing edge transverses the surface soil zone. At this time, the surface soil layer will be at field capacity with the soil holding the maximum amount of water that will not drain away due to gravity. The upper 10-centimeter layer of soil then dries at a rate calculated for sandy loam soils in the Southwest (96). The subsurface soil is always at field capacity.

j. The moisture content and temperature of the environment determine the growth and/or inactivation of pathogens.

k. Irrigation water may be pumped from groundwater influenced by irrigation, may be from the diversion of surface flows, or may be a combination of water from both sources. Variables are included in the pathway which indicate the dilution factor of pathogens present in groundwater (DILGRN) and the fraction of the total irrigation from this source (DILIRR). The number of pathogens from an external source (COUNT) can be specified.

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Manipulation of this variable can simulate repeated applications of liquid sludge by inputting a number of pathogens equal to an application of sludge while zeroing the contribution from groundwater.

l. Crop type affects transfers of pathogens from soil surface water. A fraction of the pathogens in surface soil become suspended in surface water at the beginning of irrigation. Default values for this transfer are estimates. The user may specify supportable values if they are available. While there is standing water in the field, splashing results in transfers of pathogens suspended in soil surface water to above-ground crops. On-ground crops are submerged in the irrigation water and retain a portion of suspended pathogens. The number retained is related to the area of the field occupied by the crop. Since pathogens suspended in the surface water return to the soil as irrigation water percolates into the soil, below-ground crops receive no direct transfers from soil surface water.

m. Workers enter the field during application, planting, irrigation, and harvest and directly remove surface soil which adheres to shoes, clothing and skin. Default values for direct removal are estimates of contact. The user may supply values which reflect his own experience. Note that two variables are provided, one for removals before harvest (WTDRM) and one for removal during harvest (WTDRMH).

n. Transfers from subsurface soil to surface soil do not occur when the pathway default values are used. The user may specify a value for the variable FRSUR to reflect cultivation or other physical disturbance of the soil profile. Specified transfers will occur at 2-week intervals.

o. An optional rain is included in the pathway. If requested, the rain will produce surface runoff which removes a fraction of surface-soil-associated pathogens. The values incorporated in the model for intensity and duration of rainfall result in 1/2 inch of rain on the field and produce a moderate runoff calculated for a sandy loam soil under cultivation (14).

Compartment Descriptions

Compartment 1, APPLICATION --

Liquid sludge is applied to a 1-hectare field by one of three methods. The sludge may be sprayed on (APMETH = -1.), injected 20 cm beneath the surface (APMETH = 0.0), or spread across the field either by a manure spreader or by flow type irrigation (APMETH = +1.). The user must choose one method of application for each run of the model. Each involves a different initial distribution of sludge and pathogens between Compartment 3, PARTICULATES, Compartment 8, SOIL SURFACE (by way of Compartment 5, INCORPORATION) and Compartment 12, SUBSURFACE SOIL. When liquid sludge is sprayed on, PARTICULATES are generated. When liquid sludge is ingested, the sludge bypasses the SOIL

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SURFACE and is incorporated directly into the SUBSURFACE SOIL. When liquid sludge is spread or flowed on (spread/flow is considered as a single application method), no PARTICULATES are generated and the sludge is incorporated into the SOIL SURFACE. Regardless of which application method is chosen, RESIDUE is left on application equipment at the end of compartment activities.

The model controls the initial transfers from APPLICATION to other compartments by the use of paired variables. The weight of sludge transferred by TAU13 to PARTICULATES is determined by WPAR3A when APMETH = -1. and by WPAR3B when APMETH = 1. or 0.0. Similarly, the fraction of input pathogens transferred to SUBSURFACE SOIL by TAU112 (and immediately incorporated) is determined by FSSURA when APMETH = 0.0 but by FSSURB when APMETH = -1. or +1. The pathogens not transferred by TAU112 are transferred to Compartment 5, INCORPORATION, and then to SOIL SURFACE when the field is plowed.

This compartment has a 48-hour duration to simulate the time necessary for a field to dry out after surface application of liquid sludge before INCORPORATION (plowing) and seeding can proceed. Process functions provided are those for pathogens in liquid sludge. Injected sludge and its pathogens are not affected by these process functions since TAU112 occurs early in the pathway, transferring these pathogens to SUBSURFACE SOIL.

Time of first transfer into compartment - Start of pathway.

Time of last transfer out of compartment - 48 hours into pathway.

Process function - RH01
  Activated: At the start of the pathway
  Duration: 48 hours.
  Rates: Salmonella: 0.13*N(1)/hour, for 20 < TEMP < 45 to an upper limit of 1×10^9 salmonella per kilogram (dry weight) of sludge applied. The growth of salmonella in liquid sludge is an estimate based upon 1/2 the rate of growth for E.coli in sterile sludge (76)
    -3.45*N(1)/hour, for TEMP ≥ 45. (8, 93)
    0.0*N(1)/hour, for TEMP ≤ 20.
  Ascaris: 0.00041*N(1)/hour, for 20 < TEMP < 40. (22, 31, 32, 70)
    -1.535*N(1)/hour, for TEMP ≥ 40. (7, 78)
    0.0*N(1)/hour, for TEMP ≤ 20.
  Poliorirus: -0.01*N(1)/hour, for TEMP < 45. (44, 87)
    -0.38*N(1)/hour, for TEMP ≥ 45. (88, 97)

Transfers into compartment -
  TAU01 = ASCIN, Transfer occurs at the beginning of the pathway.

Transfers out of compartment -
  TAU12 = (WTRES2/(APRATE - WPAR3__)*N(1), Transfer occurs 8 hours into the pathway.

TAU13 = (WPAR3__/APRATE)*N(1), Transfer occurs 2 hours into the pathway.
TAU15 = N(1), Transfer occurs 48 hours into the pathway.
TAU112 = FSSUR_*N(1), Transfer occurs 10 hours into the pathway.

Compartment 2, RESIDUE ON EQUIPMENT --

RESIDUE is left on equipment at the end of the APPLICATION compartment. The amount is determined by the variable WTRES2. The default value for this variable is an estimate. The material in RESIDUE compartments is assumed to dry out rapidly. The process functions assigned to this and other RESIDUE compartments reflect the effects of desiccation on the model pathogens.

Time of first transfer into compartment - 8 hours into pathway.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RHO2
  Activated: 8 hours into pathway.
  Duration: Until all pathogens are depleted or the pathway ends.
  Rates:
    Salmonella:
      0.13*N(2)/hour, for % solids of sludge $\leq$ 70 and 20 $\leq$ TEMP $\leq$ 40 to an upper limit of 1×10^9 per kilogram solids. This growth rate is 1/2 the rate of E.coli in sterile sludge. (76)
      -0.05*N(2)/hour, for 70 < % solids < 80 and TEMP < 40. (8)
      -3.45*N(2)/hour, for % solids < 80 and TEMP > 40. (8, 93)
      -0.46*N(2)/hour, for % solids $\geq$ 80. (8)
      0.0*N(2)/hour, for % solids < 80 and TEMP $\leq$ 20.
    Ascaris:
      -0.0012*N(2)/hour, for TEMP < 40 and % solids < 95. (40)
      -1.535*N(2)/hour, for 40 $\leq$ TEMP $\leq$ 50 and % solids < 95. (7, 78)
      -0.25*N(2)/hour, for % solids $\geq$ 95. (22, 40, 74)
    Poliovirus:
      -0.01*N(2)/hour, for % solids < 65 and TEMP < 45. (44, 87)
      -0.38*N(2)/hour, for TEMP > 45. (88, 97)
      -0.02*N(2)/hour, for % solids $\geq$ 65 and TEMP < 45. (87)

Transfers into compartment -
  TAU12 = (WTRES2/(APRATE-WPAR3__)*N(1), Transfer occurs 8 hours into pathway.

Transfers out of compartment - None.

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Compartment 3, PARTICULATES --

The activities described for Compartment 1 can generate airborne sludge droplets or PARTICULATES when APMETH = -1. It is assumed in all PARTICULATE compartments that the airborne material is generated at the start of activities in the compartment from which the transfer to PARTICULATES is made, in this case Compartment 1 - APPLICATION, and that the airborne material and its associated pathogens remain at the initial concentration until the generating activity ceases. The process functions in all PARTICULATES compartments are delayed to allow for maximum inhalation of pathogens during generation activities.

The user may specify the amount of sludge being transferred to this compartment by assigning a value to either WPAR3A or B. There are three compartments described by the title PARTICULATES in this pathway: Compartment 3, Compartment 6, and Compartment 7. To avoid confusion in this and other pathways a naming system was used in which the "weight transferred to PARTICULATES" is abbreviated "WTPAR" or "WPAR" and the number of the compartment concerned is appended. The shorter abbreviation is used when more information is needed to describe the variable. In this compartment, the amount of sludge which would become airborne as PARTICULATES depends on the application method. Only spray irrigation should lead to PARTICULATE generation (APMETH = -1.). Neither spread/flow irrigation nor injection (APMETH = +1. and 0.0, respectively) should result in airborne sludge droplets. Therefore, two variables are provided: WPAR3A for APMETH = -1. and WPAR3B for APMETH = +1. and 0.0. A similar system is used to identify RESIDUE transfer variables. Thus, WTPAR6 is the weight of sludge transferred to PARTICULATES in Compartment 6 and WPAR3A is the weight of sludge transferred in Compartment 3 when APMETH = -1.

The default value assigned WPAR3A was determined by assuming that PARTICULATES are generated to a level of 15 mg/m^3 in a volume extending 10 meters over the 1-hectare field. The concentration of particules and the height of the volume considered are the same in all PARTICULATES compartments but the area under the cloud differs between pathways.

The process functions for PARTICULATES are the same as for RESIDUE and reflect the effects of rapid desiccation of the airborne material and the pathogens associated with it.

Time of first transfer into compartment - 2 hours into pathway.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RHO3

Activated:	8 hours into pathway.		
Duration:	Until all pathogens are depleted or the pathway ends.		
Rates:	Salmonella:	-0.46*N(3)/hour.	(8)
	Ascaris:	-0.25*N(3)/hour.	(22, 40, 74)
	Poliovirus:	-0.38*N(3)/hour.	(88, 97)

Transfers into compartment -
TAU13 = (WPAR3__/APRATE)*N(1), Transfer occurs 2 hours into pathway.

Transfers out of compartment - None.

Compartment 4, RESIDUE ON EQUIPMENT --

RESIDUE is left on equipment at the end of the INCORPORATION compartment. The amount is determined by the variables WRES4A and B. The amount of residue left on equipment following INCORPORATION depends on the method of sludge application chosen. WRES4A is the variable used when the liquid sludge is injected (APMETH = 0.0), while WRES4B is the variable used when sludge is applied on the surface. The default values for these variables are estimates. The material in RESIDUE compartments is assumed to dry out rapidly. The process functions assigned to this and other RESIDUE compartments reflect the effects of desiccation on the model pathogens.

Time of first transfer into compartment - 52 hours into pathway.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RHO4
Activated: 69 hours into pathway.
Duration: Until all pathogens are depleted or the pathway ends.
Rates: Salmonella: -0.46*N(4)/hour. (8)
The inactivation of residue-associated salmonella is assumed to occur at the rate for salmonella in drying sludge at greater than 80 percent solids.
Ascaris: -0.25*N(4)/hour. (22, 40, 74)
Poliovirus: -0.38*N(4)/hour. (88, 97)

Transfers into compartment -
TAU54 = (WRES4__/(APRATE-WTPAR6)*N(5), Transfer occurs 52 hours into pathway.

Transfers out of compartment - None.

Compartment 5, INCORPORATION --

After sludge is applied by either the spray or spread/flow irrigation methods, it must be incorporated into the soil. Sludge applied by the injection method is effectively incorporated during APPLICATION. Regardless of which manner of applying sludge is used, the field must be plowed before being seeded. Plowing incorporates surface-applied sludge and sludge-associated pathogens evenly throughout the upper 10 centimeters of soil. This layer is the SOIL SURFACE modeled in Compartment 8. After plowing, the field is planted in one of three crops: an above-ground crop represented by hybrid tomatoes, an on-ground crop represented by zucchini squash, or a below-ground crop represented by carrots. The type of crop is determined by the variable CROP.

Sludge and sludge-associated pathogens are transferred from this compartment to Compartment 4, RESIDUE ON EQUIPMENT, by TAU54; to Compartment 6, PARTICULATES, by TAU56, and to Compartment 8, SOIL SURFACE, by TAU58. PARTICULATES are generated during the plowing activities of the compartment, so TAU56 is transferred 50 hours into the pathway. The transfer to SOIL SURFACE marks the end of INCORPORATION, 52 hours into the pathway. The sludge has now been incorporated into the soil and the associated pathogens are being affected by soil conditions. Some sludge would be left on the equipment used to spread and incorporate the sludge and to plant the crop. Transfer of this residue also occurs at the end of compartment activities, 52 hours into the pathway.

The user may control the amount of sludge transferred to RESIDUE and PARTICULATES by specifying values for the variables WRES4A or B and WTPAR6 in the input variable P-array. The amount of residue left on equipment depends on the method of sludge application chosen. WRES4A is the variable used when the sludge is injected (APMETH = 0.0), while WRES4B is the variable used when the sludge is applied on the surface. The number of pathogens associated with the weight of sludge transferred is calculated by dividing the weight of sludge transferred by the total weight of sludge in the compartment from which the transfer is being made and then multiplying by the number of pathogens in that compartment. All weights considered in transfers are dry weights since the moisture content of sludge or soil may differ in individual pathway runs. Calculations of transfers can always be found in the subroutine for the compartment from which a tranfer is made.

Time of first transfer into compartment - 48 hours into the pathway.

Time of last transfer out of compartment - 52 hours into pathway.

Process function - RH05
  Activated: 48 hours into the pathway.
  Duration: 4 hours.
  Rates: Salmonella: $0.13*N(5)$/hour, for $20 < TEMP < 45$ to an upper limit of $1x10^9$ salmonella per gram dry weight of soil. Growth of salmonella in the liquid sludge soil mixture is an estimate based on 1/2 the rate of growth for E.coli in sterile sludge. (72)
    $-3.45*N(5)$/hour, for $TEMP \geq 45$. (8, 93)
    $0.0*N(5)$/hour, for $TEMP \leq 20$.
  Ascaris: $-0.00041*N(5)$/hour, for $20 < TEMP < 40$. (22, 31, 32, 70)

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-1.535*N(5)/hour, for TEMP < 40.
(7, 54)
0.0*N(5)/hour, for TEMP < 20.
Poliovirus: -0.01*N(5)/hour, for TEMP < 45. (44, 87)
-0.38*N(5)/hour, for TEMP ≥ 45. (88, 97)

Transfers into compartment -
TAU15 = N(1), Transfer occurs 48 hours into the pathway.

Transfers out of compartment -
TAU54 = WRES4__/(APRATE - WTPAR6)*N(5), Transfer occurs 2 hours into pathway.
TAU56 = (WTPAR6/APRATE)*N(5), Transfer occurs 50 hours into the pathway.
TAU58 = N(5) - TAU54, Transfer occurs 52 hours into the pathway.

Compartment 6, PARTICULATES --

The activities described for Compartment 5 will generate airborne dust or PARTICULATES. It is assumed in all PARTICULATES compartments that the dust is generated at the start of activities in the compartment from which the transfer to PARTICUALTES is made, in this case Compartment 5 - INCORPORATION, and that the dust and its associated pathogens remain at the initial concentration until the generating activity ceases. The process functions in all PARTICULATES compartments are delayed to allow for maximum inhalation of pathogens during generation activities.

The default value assigned WTPAR6 was determined by assuming that PARTICULATES are generated to a level of 15 mg/m^3 in a volume extending 10 meters over the 1-hectare field. The concentration of particules and the height of the volume considered are the same in all PARTICULATES compartments but the area under the dust cloud differs between pathways.

The process functions for PARTICULATES are the same as for RESIDUE and reflect the effects of rapid desiccation of the airborne material and the pathogens associated with it.

Time of first transfer into compartment - 50 hours into pathway.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RHO6
Activated: 58 hours into pathway.
Duration: Until all pathogens are depleted or the pathway ends.
Rates: Salmonella: -0.46*N(6)/hour. (8)
Ascaris: -0.25*N(6)/hour. (22, 40, 74)
Poliovirus: -0.38*N(6)/hour. (88, 97)

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Transfers into compartment -
TAU56 = (WTPAR6/APRATE)*N(5), Transfer occurs 50 hours into pathway.

Transfers out of compartment - None.

Compartment 7, PARTICULATES --
This compartment simulates the effects of a windstorm. Dust is blown up from the SOIL SURFACE (TAU87); the amount can be specified by assigning a value to WTPAR7. The default value for this variable assumes 15 milligrams of sludge-fertilized soil per cubic meter of air in a 10-meter high volume above the 1-hectare field. The time of the storm can also be controlled. The variable TWIND may be assigned a value which places the storm at any time between 57 days into the pathway and the time of harvest (THARV). TWIND may also be used to exclude a windstorm from pathway occurrences. This is done by assigning the value -2. to the variable.

Process functions for this compartment are delayed 1 hour after generation. The rates of inactivation simulate rapid drying.

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Time of first transfer into compartment - TWIND.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RHO7
Activated: TWIND + 1 hour
Duration: Until all pathogens are depleted or the pathway ends.
Rates: Salmonella: -0.46*N(7)/hour. (8)
Ascaris: -0.25*N(7)/hour. (22, 40, 74)
Poliovirus: -0.38*N(7)/hour. (88, 97)

Transfers into compartment -
TAU87 = (WTPAR7/APRATE)*N(8), Transfer occurs at TWIND.

Transfers out of compartment - None.

Compartment 8, SOIL SURFACE --
The first 10 centimeters of soil are the SOIL SURFACE. The soil in this compartment is subjected to a weekly moisture cycle which begins with sludge application; the first irrigation of the field. The soil is at field capacity (20 percent weight/weight) after each irrigation and dries to the wilting point (4 percent weight/weight) between irrigations. Pathogen process functions are tied to the irrigation cycle. The rate of growth or inactivation of pathogens is dependent on the ambient temperature of the environment and on the available water. The ambient temperature is constant throughout the pathway and is set by the variable TEMP. The available water is a function of the time elapsed since the last irrigation.

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Sludge fertilizer and pathogens are first transferred into this compartment from the INCORPORATION compartment by TAU58. As the pathway progresses there are several other transfers into this compartment. At irrigation, water from Compartment 16, IRRIGATION WATER, is transferred to Compartment 13, SOIL SURFACE WATER. This water then percolates into the soil, transferring pathogens to SOIL SURFACE by TAU138. The pathogens involved in this transfer either may be soil pathogens which become suspended in the water during irrigation, a phenomenon simulated by TAU813, or may be pathogens introduced with the irrigation water itself. In a similar manner, after pathogens have been transferred to CROP SURFACE, some will be returned to SOIL SURFACE when gravity and wind cause dust on above-ground crops to fall to the ground (TAU118). If the field is cultivated after planting, pathogens which have been carried to SUBSURFACE SOIL (Compartment 12) will be transferred to the SOIL SURFACE as the ground is turned. This is simulated by TAU128.

There is one other way for pathogens to enter this compartment. The user may place an initial pathogen population in any pathway compartment by specifying the compartment number and the desired population in the POPL variable of the $ARGS name list. The mechanism for handling variable specification is fully described in the user's manual for the program (Appendix A). Specifying an initial pathogen population allows the user to examine the effects of several sludge applications. The final compartment populations of one model run would be input as initial populations in the next run. Environmental conditions may be unique for each run, or standard default values may be used.

Pathogens are transferred from this compartment into Compartment 7, PARTICULATES, by TAU87; Compartment 12, SUBSURFACE SOIL, by TAU812; Compartment 11, CROP SURFACE, by TAU811; Compartment 13, SOIL SURFACE WATER, by TAU813; Compartment 10, DIRECT REMOVAL, by TAU810; and to Compartment 9, SURFACE RUNOFF, by TAU89. PARTICULATES are generated by a windstorm that occurs at a user-specifiable time, TWIND. A further description of the windstorm is found in the preceding description of Compartment 7. The transfer from SOIL SURFACE to SUBSURFACE SOIL occurs after each irrigation as irrigation water percolates below the 10-centimeter mark which separates SOIL SURFACE from SUBSURFACE SOIL. The time of this transfer is controlled by the infiltration rate of SOIL SURFACE WATER, a parameter the user may specify in variable FILTR8. The transfer of soil and soil pathogens to CROP SURFACE is different for each type of crop. As explained in the General Considerations for this pathway, above-ground crops are dusted with soil during the arbitrary windstorm, while on-ground and below-ground crops would not be involved in this transfer. At harvest, time THARV, all three types of crops will be contaminated with soil. The fraction of the total pathogen population in Compartment 8 which is transferred to the designated crops is specified in the variables FCROP1, FCROP2, and FCROP3.

Since only one crop is grown in the field during a particular model run, the user must be careful in this pathway to match specified variables to crop type. Inputting a user-specified value in position 27 of the P-array when running this pathway for CROP = 0.0 (on-ground crop type)

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will result in the use of the default value for FCROP2 in TAU811. Position 27 is FCROP1, a variable only used when CROP = +1. The user would have to specify the value of position 28 to make a change when looking at on-ground crops. The linking of variables occurs for many parameters.

Soil and soil pathogens are suspended in irrigation water while it is lying on the surface of the field and is considered in Compartment 13, SOIL SURFACE WATER. This soil and its associated pathogens would return to SOIL SURFACE as the irrigation water percolates into the ground. Workers will enter the field periodically and will carry dirt away with them. This DIRECT REMOVAL is a weekly event until harvest. Two variables (WTDRM and WTDRMH) control the amount of soil and pathogens transferred to DIRECT REMOVAL because it is assumed that more soil is removed during harvest than during inspection.

The transfer to SURFACE RUNOFF simulates the effects of a rain and occurs at TRAIN. The rain which produces runoff is an arbitrary event which does not occur under default conditions. The user must set TRAIN to a positive number. The user may control the number of pathogens removed from the pathway by TAU89 by specifying the value of FRRAIN.

Time of first transfer into compartment - 52 hours into pathway.

Time of last transfer out of compartment - THARV.

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Process function - RH08
    Activated: 52 hours into the pathway.
    Duration: Until the end of the pathway.
    Rates: Salmonella:
        0.07*N(8)/hour, for 20 ≤ TEMP < 45 and 0 < TIRRG ≤ 3.5 days. The growth of salmonella is assumed to occur at one-half the rate for *E.coli* in the sterile compost. (62)
        -0.12*N(8)/hour, for 20 ≤ TEMP < 45 and 3.5 < TIRRG ≤ 5.5 days. (23, 72, 73)
        -0.46*N(8)/hour, for 20 ≤ TEMP ≤ 45 and 5.5 < TIRRG ≤ 7 days. (8)
        -3.45*N(8)/hour, for TEMP ≥ 45 and any time. (8, 93)
        0.0*N(8)/hour, for TEMP < 20 and any time. No changes in pathogen population are assumed for temperatures less than 20°C.
    Ascaris:
        -0.0005*N(8)/hour, for TEMP < 40 and 8 hours < TIRRG ≤ 5.5 days. (83)
        -1.54*N(8)/hour, for 40 ≤ TEMP ≤ 50 and 8 hours < TIRRG ≤ 5.5 days. (7, 78)
        -0.25*N(8)/hour, for TIRRG > 5.5 days and any temperature. (22, 40, 74)
        0.0*N(8)/hour, for TIRRG < 8 hours and any TEMP.

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Poliovirus: -0.005*N(8)/hour, for 15 < TEMP < 45 and 8 hours < TIRRG ≤ 6.5 days. (27, 96)
-0.027*N(8)/hour, for TEMP < 45 and TIRRG > 6.5 days. (87, 96)
-0.38*N(8)/hour, for TEMP ≥ 45 and any time. (88, 97)
-0.00087*N(8)/hour, for TEMP < 15 and 8 hours < TIRRG < 6.5 days. (96)
0.0*N(8)/hour, for TEMP < 45 and TIRRG < 8 hours.

Transfers into compartment -
TAU58 = N(1) - TAU54, Transfer occurs 52 hours into pathway.
TAU118(above-ground crop) = 0.0017*N(11).
TAU118(other crops) = 0.0*N(11), Transfers begin at TWIND and continue for 5 days.
TAU128 = FRSUR*N(12), Transfer occurs at 2 week intervals if FRSUR > 0 and cultivation takes place.
TAU138 = N(13) - TAU1311, Transfer occurs at TIRRG + DEPTH/FILTR8 for each irrigation.

Transfers out of compartment -
TAU89 = FRRAIN*N(8), Transfer occurs only if there is a rain and then at the time of rain, TRAIN.
TAU87 = (WTPAR7/APRATE)*N(8), Transfer occurs at TWIND.
TAU810(before harvest) = (WTDRM/APRATE)*N(8), Transfer occurs 168 hours into the pathway and then at weekly intervals until THARV.
TAU810(harvest) = (WTDRMH/APRATE)*N(8), Transfer occurs at THARV.
TAU811(above-ground crop) = FCROP1*N(8), Transfer occurs at TIRRG (transferred during each irrigation).
TAU811(on-ground crop) = FCROP2*N(8), Transfer occurs at TIRRG.
TAU811(below-ground crop) = FCROP3*N(8), Transfers occur at THARV.
TAU812 = SUBSOL*N(8), Transfer occurs at TIRRG + DEPTH/FILTR8 (transferred during each irrigation).
TAU813 = SUSPND*N(8), Transfer occurs at TIRRG (transferred during each irrigation) and at TRAIN.

Compartment 9, SURFACE RUNOFF --

Pathogens are transferred into this compartment from Compartment 8, SOIL SURFACE, only if a rain occurs. The compartment exists to show that the transfer occurs and to keep track of the pathogen population removed. No process functions have been defined for this compartment. It is beyond the scope of this model to follow pathogens washed from a field by storm runoff.

Time of first transfer into compartment - TRAIN.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

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Process function - RH09
Activated: TRAIN
Duration: Until all pathogens are depleted or the pathway ends.
Rates: Salmonella: 0.0*N(9)/hour.
Ascaris: 0.0*N(9)/hour.
Poliovirus: 0.0*N(9)/hour.

Transfers into compartment -
TAU89 = FRRAIN*N(8), Transfer occurs at TRAIN.

Transfers out of compartment - None.

Compartment 10, DIRECT REMOVAL --

Surface soil and the pathogens associated with it will adhere to the shoes, clothing, and skin of people who enter the field. These pathogens are directly removed from the field. Two variables determining the weight of soil transferred from SOIL SURFACE to DIRECT REMOVAL have been defined. One, designated WTDRM, determines the weight transferred to workers in the field supervising irrigation. This variable is used in TAU810 at 168 hours into the pathway and then weekly until the time of harvest (which is determined by the variable THARV). The other variable WTDRMH is used in TAU810 at the time of harvest. The default value for WTDRMH is larger than the default value for WTDRM. This larger value was chosen to reflect the greater possible contact with soil during harvest.

Time of first transfer into compartment - 54 hours into pathway.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted following the last transfer into the compartment.

Process functions - RH06
Activated: 54 hours into pathway then at weekly intervals until harvest (THARV) and at harvest.
Duration: 24 hours after each transfer.
Rates: Salmonella: N(6) = 0.0, after 24 hours.
Ascaris: N(6) = 0.0, after 24 hours.
Poliovirus: N(6) = 0.0, after 24 hours.

Transfers into compartment -
TAU810(before harvest) = (WTDRM/APRATE)*N(8), Transfer occurs 54 hours into the pathway and then at weekly intervals until THARV.
TAU810(harvest) = (WTDRMH/APRATE)*N(8), Transfer occurs at THARV.

Transfers out of compartment - None.

Compartment 11, CROP SURFACE --

Before each pathway run the user must specify one crop type. The default value for the variable CROP specifies the above-ground type

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represented by bush tomatoes. An on-ground crop represented by zucchini squash and a below-ground crop represented by carrots are the other choices. The crop types are described in the General Considerations for this pathway (items e and g). Table 4c presents a convenient summary of the parameters defining each crop.

The type of crop controls the transfers into and out of this compartment. Above-ground crops contact pathogens in dust generated from the SOIL SURFACE, a transfer modeled by TAU811 which occurs at TWIND, and from SOIL SURFACE WATER which splashes up during irrigation, a transfer modeled by TA1311. On-ground crops are not affected by blown dust since they are essentially at equilibrium with surface soil but the transfer from SOIL SURFACE WATER is greater than for above-ground crops. On-ground crops are covered by irrigation water during each irrigation. Below-ground crops lie half in the surface soil and half in the subsurface soil. No dust or irrigation water reaches them. All three crops contact pathogens transferred from SOIL SURFACE by TAU811 at harvest. This represents the normal dirt found on all fresh vegetables. Only below-ground crops also receive a transfer from SUBSURFACE SOIL by TA1211.

Pathogens are transferred out of this compartment back to SOIL SURFACE by TAU118 as dust and vegetation fall from tomato and zucchini plants to the ground. Pathogens transfer from on-ground CROP SURFACE to SOIL SURFACE WATER by TA1113 at the start of each irrigation when pathogens become suspended in the overlying water. All pathogens associated with the crop are transferred to Compartment 15, HARVEST, by TA1115 at THARV. At that time all crops are physically removed from the field.

Time of first transfer into compartment - TIRRG.

Time of last transfer out of compartment - THARV.

Process function - RH011
  Activated: TIRRG.
  Duration: Until THARV.
  Rates: Salmonella: -0.96*N(11)/hour, for above-ground and on-ground crops. (72, 73)
    0.0*N(11)/hour, for below-ground crops.
  Ascaris: -1.54*N(11)/hour, for above-ground and on-ground crops. (7, 78)
    0.0*N(11)/hour, for below-ground crops.
  Poliovirus: -0.069*N(11)/hour, for above-ground and on-ground crops. (49)
    0.0*N(11)/hour, for below-ground crops.

Transfers into compartment -
  TAU811(above-ground crop) = FCROP1*N(8). Transfer occurs at TWIND and at THARV.
  TAU811(on-ground crop) = FCROP2*N(8).
  TAU811(below-ground crop) = FCROP3*N(8), Transfers occur at THARV.

TA1211 = FSSCRP*N(12), Transfer occurs at THARV for below-ground crops.
TA1311(above-ground crop) = FSUR1*N(13).
TA1311(on-ground crop) = FSUR2*N(13).
TA1311(below-ground crop) = FSUR3*N(13), Transfers occurs at TIRRG (transferred during each irrigation).

Transfers out of compartment -
TAU118(above-ground crop) = 0.0017*N(11).
TAU118(other crops) = 0.0*N(11), Transfers begin at TWIND and continue for 5 days.
TA1113 = N(11), Transfer occurs only if CROP = 0.0 (on-ground) and then at each TIRRG after day 57 (the time when crops are present).
TA1115 = N(11), Transfer occurs at THARV.

Compartment 12, SUBSURFACE SOIL--

This compartment represents the soil from 10 to 60 centimeters below the surface. This SUBSURFACE SOIL is at constant moisture (field capacity, 20 percent weight/weight) and temperature (15°C). When the injection method of liquid sludge application is chosen (APMETH = 0.0), the sludge and its associated pathogens are transferred directly into the compartment during APPLICATION by TAU112. A pair of variables, FSSURA and FSSURB, determine the fraction of ASCIN which is transferred directly to SUBSURFACE SOIL. When APMETH is set to 1. or -1. pathogens from the sludge-fertilized upper 10 centimeters of soil are transferred into this compartment with percolating irrigation water. The fraction of the total SOIL SURFACE (Compartment 8) pathogen population transferred is determined by the variable SUBSOL. The time of the transfer by TAU812 is controlled by the depth of irrigation water which must soak in (DEPTH) and the rate of water infiltration (FILTR8), but the transfer occurs after each irrigation.

There are three possible transfers out of this compartment. Pathogens may be transferred to Compartment 14, GROUNDWATER, by TA1214. The variable, FRGRND, which specifies the fraction of total SUBSURFACE SOIL pathogens transferred is set to zero under default conditions. The 6 centimeters of sludge or irrigation water applied under default conditions would only penetrate approximately 60 centimeters, precluding transfer to GROUNDWATER. The user should specify a value for FRGRND if DEPTH is set to more than 6 centimeters.

Pathogens may be transferred to Compartment 8, SOIL SURFACE, by TAU128 if the user specifies a positive value for the variable FRSUR. This variable indicates that cultivation is to be simulated and sets the fraction of transfer. Cultivation, once flagged, occurs at 2-week intervals from the start of the pathway.

Pathogens may be transferred to Compartment 11, CROP SURFACE, by TA1211 if the below-ground crop type is being modeled. This transfer would occur at harvest.

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Time of first transfer into compartment - 10 hours into pathway.

Time of last transfer out of compartment - THARV.

Process function - RH012
Activated: 10 hours into pathway.
Duration: Until THARV.
Rates: Salmonella: -0.012*N(12)/hour. (23, 72, 73)
Ascaris: -0.00053*N(12)/hour. (83)
Poliovirus: -0.0049*N(12)/hour. (27, 96)

Transfers into compartment -
TAU112 = FSSUR_*N(1), Transfer occurs 10 hours into the pathway.
TAU812 = SUBSOL*N(8), Transfer occurs at TIRRG + DEPTH/FILTR8 (transferred during each irrigation).

Transfers out of compartment -
TAU128 = FRSUR*N(12), Transfer occurs at 2-week intervals if FRSUR > 0 and cultivation takes place.
TA1211 = FSSCRP*N(12), Transfer occurs at THARV for below-ground crops.
TA1214 = FRGRND*N(12), Transfer occurs at TIRRG + 1 hour, then weekly until THARV and also at TRAIN.

Compartment 13, SOIL SURFACE WATER --

Irrigation in this model involves flooding the field with water or sludge to a uniform depth (specified by the variable DEPTH) and then allowing the water to infiltrate the soil at a constant rate (specified by the variable FILTR8). The water transfers into SOIL SURFACE WATER from Compartment 13, IRRIGATION WATER, by TA1613 and may carry with it a pathogen load. Pathogens in SOIL SURFACE and on the CROP SURFACE of on-ground crops will become suspended in the overlying water. These transfers from Compartment 8 and Compartment 11, respectively, will occur for each TIRRG.

The variable TIRRG is used in several ways in the model. Its value is incremented by 168 hours each time it is used so that irrigation occurs at weekly intervals after the first irrigation (sludge application). The variable is also used in the process functions for Compartment 8 to keep track of the time elapsed since the last irrigation.

Pathogens transfer back to Compartment 8, SOIL SURFACE, and Compartment 11, CROP SURFACE, when the irrigation water soaks into the soil. Although this would normally be a gradual process, TAU138 and TA1311 occur at the end of each irrigation, as a single transfer to each compartment.

Time of first transfer into compartment - TIRRG.

Time of last transfer out of compartment - Transfers are made from this compartment following each irrigation. The last transfer will follow the last irrigation before harvest. The exact time depends on the value of THARV.

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Process function - RHO13

Activated: TIRRG (with each irrigation).

Duration: TIRRG + (DEPTH/FILTR8).

Rates:
- Salmonella: 0.23*N(13)/hour. A 3-hour generation time is assumed for growth of salmonella suspended in irrigation water.
- Ascaris: 0.0*N(13)/hour.
- Poliovirus: 0.0*N(13)/hour. No change is assumed for ascaris and poliovirus suspended in irrigation water.

Transfers into compartment -

TAU813 = SUSPND + N(8), Transfer occurs at TIRRG (transferred during each weekly irrigation) and at TRAIN.

TA1113 = N(11), Transfer occurs only if CROP = 0.0(on-ground) and then at each TIRRG after day 57 (the time when crops are present).

TA1613 = N(1), Transfer occurs at each TIRRG.

Transfers out of compartment -

TAU138 = N(13) - TA1311, Transfer occurs at TIRRG + DEPTH/FILTR8 for each TIRRG.

TAU97(above-ground crop) = FSUR1*N(13).

TAU97(on-ground crop) = FSUR2*N(13).

TAU97(below-ground crop) = FSUR3*N(13), Transfers occur at TIRRG, (transferred during each irrigation).

Compartment 14, GROUNDWATER --

Sludge applied to a field may contaminate groundwaters if surface water percolates deeply enough. The default values incorporated into the model preclude such contamination but, as explained in Compartment 12, the user may specify a transfer of pathogens to GROUNDWATER in order to model the effects of heavy irrigation.

Pathogens transferred to GROUNDWATER would be inactivated slowly as shown in the process functions listed below. Pathogens would also be dispersed throughout the aquifer. The user may determine the effects of dispersion by specifying a value for DILGRN. This variable is included in the equation for TA1416 and affects the pathogen number transferred to Compartment 16, IRRIGATION WATER. Another variable in the equation for TA1416 is DILIRR. It determines what fraction of the water used for irrigation is from GROUNDWATER by specifing the fraction of the pathogens present that will be transferred. The default values for these variables were not chosen to model any particular situation. One-half of the water in Compartment 16 is from GROUNDWATER, while the aquifer dilutes incoming percolation by 1 x 10^6 when default values are used.

Time of first transfer into compartment - TIRRG + 1 hour or TRAIN, whichever occurs first.

Time of last transfer out of compartment - Transfers are made from this compartment before each irrigation. The last transfer will

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occur just before the last irrigation to precede harvest. The exact time depends on the value of THARV.

Process function - RH014
Activated: At the time of first transfer in.
Duration: Until end of pathway.
Rates: Salmonella: -0.012*N(14)/hour. (23, 72, 73)
Ascaris: -0.00053*N(14)/hour. (83)
Poliovirus: -0.012*N(14)/hour. (95)

Transfers into compartment -
TAU811 = FRGRND*N(12), Transfer occurs at TIRRG + 1 hour, then weekly until THARV and also at TRAIN.

Transfers out of compartment -
TA1416 = DILIRR*DILGRN*N(14), Transfer occurs at TIRRG.

Compartment 15, HARVEST --

This compartment was originally designed to simulate harvesting of the crop and those processes which are often a part of handling raw vegetables, such as storage and washing. These processes are now included in vegetable-exposure risk calculations discussed in Section 6. No process functions are defined. Pathogens are transferred into this compartment from Compartment 11, CROP SURFACE, by TA1115. The transfer represents the physical removal of mature crops from the field, or harvest. The calculations necessary to determine the number of pathogens per crop unit of harvested vegetables are performed in this compartment. This number is output in position 38 of Pathway 11's P-array. It is this number which is used by the vegetable-exposure risk calculations.

Significant calculations - The number of pathogens per crop unit (FPCU) equals:

N(13)/5.3191E + 4, for above-ground crops.
N(13)/4.8E + 4, for on-ground crops.
N(13)/1.968E + 5, for below-ground crops.

A crop unit is one tomato, zucchini, or carrot. The number in the numerator of the fractions listed above is the number of crop units which would be grown in the 1-hectare field when the assumptions as to size and plant spacing listed in Table 4c are followed.

Time of first transfer into compartment - THARV.

Time of last transfer out of compartment - There are no transfers out of this compartment, which is the last in the pathway. Consideration of the compartment ends when the pathway terminates.

Process function - RH015
Activated: THARV.
Duration: 24 hours.

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Rates: Salmonella: 0.0*N(15)/hour.
Ascaris: 0.0*N(15)/hour.
Poliovirus: 0.0*N(15)/hour.

No process functions are defined for this compartment. The compartment was orginally designed to simulate the effects of commercial food processes on pathogens. These processes are now part of the vegetable-exposure risk calculation.

Transfers into compartment -
TA1115 = N(11), Transfer occurs at THARV.

Transfers out of compartment - None.

Compartment 16, IRRIGATION WATER--

In this compartment water from two sources is combined. Water is transferred into the compartment from GROUNDWATER by TA1416 and from an EXTERNAL SOURCE by TAU016. GROUNDWATER represents well water used here for irrigation. It may contain pathogens which have been carried through SUBSURFACE SOIL by deep percolation (TA1214). EXTERNAL SOURCE represents surface flows used for irrigation. This water may also contain pathogens. The user may specify the level of contamination by assigning a value to the variable COUNT. COUNT may be set to simulate weekly application of liquid sludge by the spread/flow irrigation method. This method is essentially irrigation with a rather highly contaminated EXTERNAL SOURCE water. DILIRR and DILGRN should both be set to 0.0 if weekly sludge irrigation is being modeled.

EXTERNAL SOURCE is not defined as a pathway compartment since the scope of the model does not consider water pollution other than the possible additive effects of using contaminated water on a sludge-fertilized field. The IRRIGATION WATER compartment has a very short duration and no process functions have been defined. The compartment does not represent a physical part of the environment but rather the transition between several states. As soon as the waters are mixed they become SOIL SURFACE WATER represented by Compartment 13. This transfer is accomplished by TA1613 at weekly intervals.

Time of first transfer in compartment - TIRRG.

Time of last transfer out of compartment - Transfers are made from this compartment for each irrigation. The last transfer will occur for the last irrigation before harvest. The exact time depends on the value of THARV.

Process function - RH016
Activated: TIRRG.
Duration: 1 hour.
Rates: Salmonella: 0.0*N(16)/hour.
Ascaris: 0.0*N(16)/hour.
Poliovirus: 0.0*N(16)/hour.

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Transfers into compartment -

TAU016 = COUNT, Transfer occurs prior to TIRRG.
TA1416 = DILIRR*DILGRN*N(14), Transfer occurs prior to TIRRG.

Transfers out of compartment -

TA1613 = N(16), Transfer occurs at each TIRRG.

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New Masters 359G
JOB A
Symbiotics

PATHWAY 12 - SLUDGE APPLICATION PATHWAY - LIQUID SLUDGE USED AS FERTILIZER FOR A GRAZED PASTURE

General Considerations

This pathway describes the fate of sewage sludge pathogens after the application of raw or anaerobically digested liquid sludge to a 1-hectare pasture planted in a forage crop, such as alfalfa or fescue, and grazed by cattle at the time of application. Figure 12 shows the process compartments and transfers which define this application regime. The differential equations which describe this pathway are presented in Table 12a. Each process function and transfer function is defined in the following section. Table 12b lists the definitions of and default values for the input variables used to define environmental factors. The general considerations and assumptions discussed below were made to facilitate model development.

a. The pathway will run for one 30-day month. It is possible to look at a longer period of time by using the final pathogen counts in each compartment as the initial conditions of each compartment in a subsequent run. This is done by specifying each compartment number and the desired pathogen population for each compartment in the POPL variable of the $ARGS name list. The mechanism for setting initial pathogen populations is described in the user's manual for the program (Appendix A).

b. The ambient temperature of the environment is specified for each model run by the variable TEMP and remains constant throughout a run. The default ambient temperature is 20°C.

c. The amount of sludge applied to the pasture (APRATE) and the concentration of pathogens in that sludge (ASCRS) are user-specifiable variables. The default values are based on adding 1.1 centimeters of sludge at 5 percent solids or 5607 kilograms of sludge to each hectare of pasture land each month (the equivalent of 30 tons of sludge per acre per year) (48). The model accommodates three methods of liquid sludge application: injection 8 inches under the surface, spray irrigation, or spread/flow irrigation. The default values for the number of pathogens in applied sludge reflect a conservative "worst case" by being equal to the concentration of each pathogen in raw sludge (1, 4, 28, 32, 77). The value of output variable PTOTL in position 17 of Pathway 10's (Sludge Treatment Pathway - Liquid Sludge) P-array is equal to the number of pathogens per kilogram of sludge at the end of sludge treatment. The user may run Pathway 10 for one of the three pathogens using variable values which approximate conditions at a particular treatment facility and then use the output value of PTOTL as the input value for ASCRS in this pathway. In this way a treatment and an application pathway may be linked and a selected pathogen followed from sewage influent to consumer.

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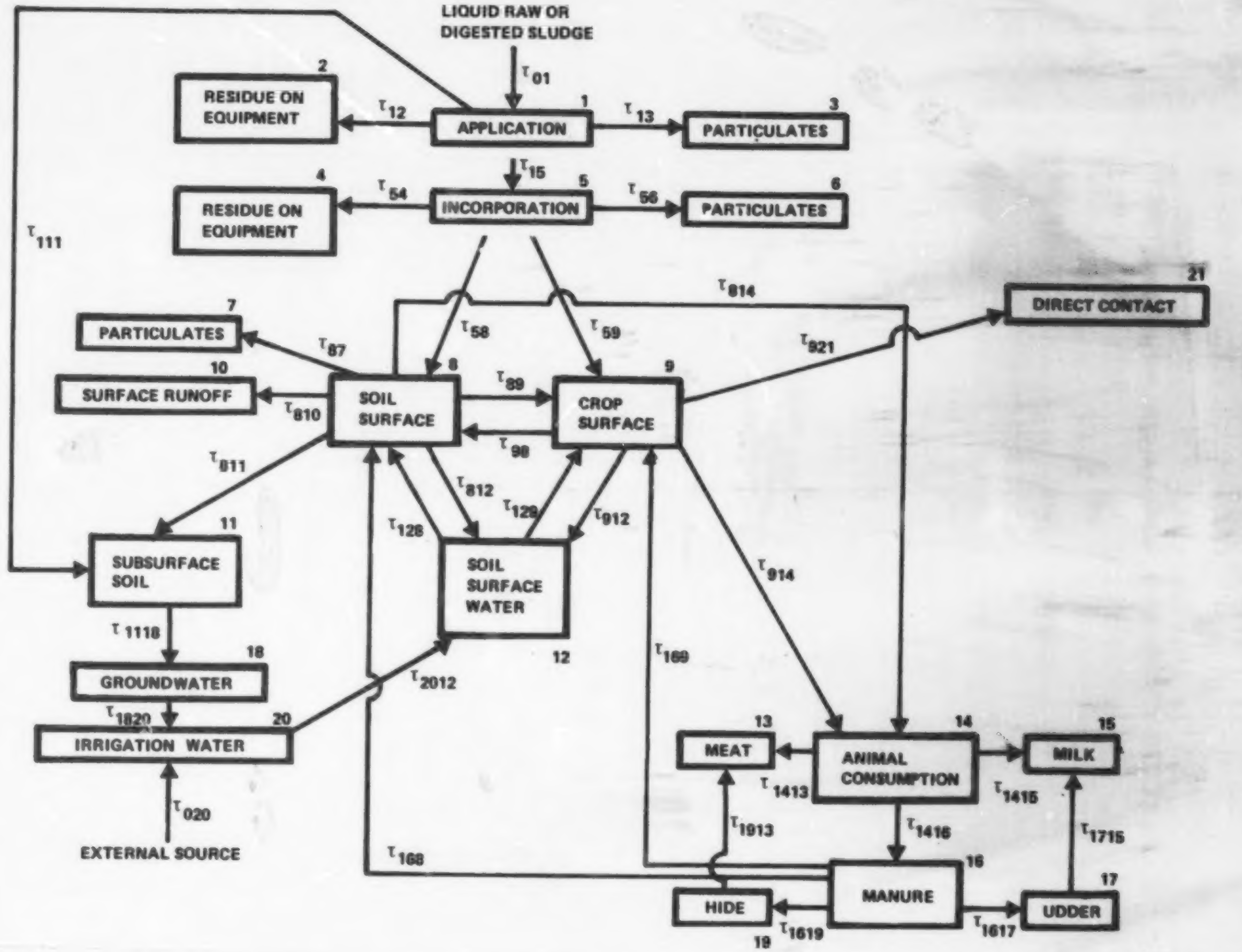
LIQUID RAW OR DIGESTED SLUDGE
τ_{01}
1 APPLICATION
τ_{12}
2 RESIDUE ON EQUIPMENT
τ_{13}
3 PARTICULATES
τ_{15}
5 INCORPORATION
τ_{54}
4 RESIDUE ON EQUIPMENT
τ_{56}
6 PARTICULATES
τ_{111}
τ_{814}
21 DIRECT CONTACT
τ_{58}
τ_{59}
τ_{921}
7 PARTICULATES
τ_{87}
10 SURFACE RUNOFF
τ_{810}
8 SOIL SURFACE
τ_{89}
τ_{98}
9 CROP SURFACE
τ_{811}
τ_{812}
τ_{128}
τ_{129}
τ_{912}
11 SUBSURFACE SOIL
12 SOIL SURFACE WATER
τ_{914}
τ_{1118}
18 GROUNDWATER
τ_{169}
τ_{2012}
τ_{1820}
20 IRRIGATION WATER
τ_{020}
EXTERNAL SOURCE
13 MEAT
14 ANIMAL CONSUMPTION
15 MILK
τ_{1413}
τ_{1415}
τ_{1913}
τ_{1416}
τ_{1715}
τ_{168}
16 MANURE
17 UDDER
19 HIDE
τ_{1619}
τ_{1617}

Figure 12. Sludge Application Pathway - Liquid Sludge Used as Fertilizer for a Grazed Pasture

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TABLE 12a. DIFFERENTIAL EQUATIONS FOR PATHWAY 12

SLUDGE APPLICATION PATHWAY - LIQUID SLUDGE USED AS FERTILIZER FOR GRAZED PASTURE

$$\dot{N}_1 = \tau_{01} - \tau_{12} - \tau_{13} - \tau_{15} - \tau_{111} + \rho_1$$

$$\dot{N}_2 = \tau_{12} + \rho_2$$

$$\dot{N}_3 = \tau_{13} + \rho_3$$

$$\dot{N}_4 = \tau_{54} + \rho_4$$

$$\dot{N}_5 = \tau_{15} - \tau_{54} - \tau_{56} - \tau_{58} - \tau_{59} + \rho_5$$

$$\dot{N}_6 = \tau_{56} + \rho_6$$

$$\dot{N}_7 = \tau_{87} + \rho_7$$

$$\dot{N}_8 = \tau_{58} + \tau_{98} + \tau_{128} + \tau_{168} - \tau_{87} - \tau_{89} - \tau_{810} - \tau_{811} - \tau_{812} - \tau_{814} + \rho_8$$

$$\dot{N}_9 = \tau_{59} + \tau_{89} + \tau_{129} + \tau_{169} - \tau_{98} - \tau_{912} - \tau_{914} - \tau_{921} + \rho_9$$

$$\dot{N}_{10} = \tau_{810} + \rho_{10}$$

$$\dot{N}_{11} = \tau_{111} + \tau_{811} - \tau_{1118} + \rho_{11}$$

$$\dot{N}_{12} = \tau_{812} + \tau_{912} + \tau_{2012} - \tau_{128} - \tau_{129} + \rho_{12}$$

$$\dot{N}_{13} = \tau_{1413} + \tau_{1913} + \rho_{13}$$

$$\dot{N}_{14} = \tau_{814} + \tau_{914} - \tau_{1413} - \tau_{1415} - \tau_{1416} + \rho_{14}$$

$$\dot{N}_{15} = \tau_{1415} + \tau_{1715} + \rho_{15}$$

TABLE 12a. (concluded)

$$\dot{N}_{16} = \tau_{1416} - \tau_{168} - \tau_{169} - \tau_{1617} - \tau_{1619} + \rho_{16}$$

$$\dot{N}_{17} = \tau_{1617} - \tau_{1715} + \rho_{17}$$

$$\dot{N}_{18} = \tau_{1118} - \tau_{1820} + \rho_{18}$$

$$\dot{N}_{19} = \tau_{1619} - \tau_{1913} + \rho_{19}$$

$$\dot{N}_{20} = \tau_{020} + \tau_{1820} - \tau_{2012} + \rho_{20}$$

$$\dot{N}_{21} = \tau_{921} + \rho_{21}$$

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TABLE 12b. VARIABLES FOR PATHWAY 12

SLUDGE APPLICATION PATHWAY - LIQUID SLUDGE USED AS FERTILIZER FOR GRAZED PASTURE

POSITION	DEFAULT VALUE	VARIABLES	DEFINITION
		INPUT VARIABLES	
1	1.95E+7 4.95E+2 6.52E+7	ASCRS	Number of pathogens per kilogram of applied sludge.
2	5.607E+3	APRATE	Application rate of sludge in kilograms per hectare.
3	ASCRS*APRATE	ASCIN	Total number of pathogens entering pathway. If present, overrides first two variables
4	20.	TEMP	Ambient temperature throughout pathway in degrees Celsius.
5	+1.	APMETH	Method of applying sludge: +1. = spread/flow 0. = injection -1. = spray.
6	+1.	COW	Animal type: +1. = milk cow -1. = meat cow.
7	-2.	TRAIN	Time in hours of arbitrary rain. (If -2., there is no rain.)
8	0.017 0.0085 0.017	FRAIN	Fraction of total pathogens transferred from Soil Surface to Surface Runoff by rain.
9	6.	DEPTH	Depth of Irrigation Water in centimeters.
10	2.	FILTR8	Infiltration rate of Soil Surface Water into soil in centimeters per hour.
11	1.0E-6	GNDIL	Groundwater and use dilution.
12	0.5	FRGIR	Fraction of Irrigation Water from Groundwater.

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TABLE 12b. (continued)

POSITION	DEFAULT VALUE	VARIABLES	DEFINITION
13	0.0	EXTRN	External Source pathogen input into irrigation water (total population).
14	10.	WTRES2	Dry weight of sludge in kilograms left as residue on equipment used for Application.
15	15.	WPAR3A	Dry weight of particulates in kilograms generated by sludge Application for APMETH = -1.
16	0.0	WPAR3B	Dry weight of particulates in kilograms generated by sludge Application for APMETH = +1. or 0.0.
17	1.	FSSURA	Fraction of ASCIN transferred to Subsurface Soil during sludge Application when APMETH = 0.0.
18	0.0	FSSURB	Fraction of ASCIN transferred to Subsurface Soil during sludge Application when APMETH = +1. or -1.
19	0.0	WRES4A	Dry weight of sludge in kilograms left as residue on equipment used during Incorporation when APMETH = 0.0.
20	5.	WRES4B	Dry weight of sludge in kilograms left as residue on equipment used during Incorporation when APMETH = +1. or -1.
21	15.	WTPAR6	Dry weight of particulates in kilograms generated by Incorporation.
22	0.7	TINCSR	Fraction of sludge transferred to Soil Surface during Incorporation.

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TABLE 12b. (continued)

POSITION	DEFAULT VALUE	VARIABLE	DEFINITION
23	5.	WTPAR7	Dry weight of particulates in kilograms generated by milling cows.
24	0.00001	SSTCS	Fraction of transfer from Soil Surface to Crop Surface.
25	0.1 0.05 0.1	SSTSSW	Fraction of transfer from Soil Surface to Soil Surface Water.
26	0.001 0.0 0.83	SSTSSS	Fraction of transfer from Soil Surface to Subsurface Soil.
27	0.01	CSTSS	Fraction of transfer from Crop Surface to Soil Surface.
28	0.5	CSTSSW	Fraction of transfer from Crop Surface to Soil Surface Water.
29	0.0001	CSTDC	Fraction of transfer from Crop Surface to Direct Contact.
30	0.1 0.05 0.1	SSWTCS	Fraction of transfer from Soil Surface Water to Crop Surface.
31	0.0	SSSTGW	Fraction of transfer from Subsurface Soil to Groundwater.
32	13.2	SCNSMP	Weight in kilograms of soil consumed by twelve cows each day.
33	84.	FORAG	Weight in kilograms of dry forage consumed by twelve cows each day.
34	0.06	FSLDGE	Fraction of forage which is sludge.
35	0.7	TMTSS	Fraction of transfer from Manure to Soil Surface.

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TABLE 12b. (continued)

POSITION	DEFAULT VALUE	VARIABLE	DEFINITION
36	-2.0	TSLOTR	Time of slaughter in days. (If -2., there is no slaughter.)
37	0.001	TMTH	Fraction of transfer from Manure to Hide.
38	0.1	HTM	Fraction of transfer from Hide to Meat at slaughter.
39	0.001	TMTU	Fraction of transfer from Manure to Udder.
40	0.05	UTM	Fraction of transfer from Udder to Milk.
41	0.0	DTCTMT	Fraction of transfer directly from Animal Consumption to Meat.
42	0.0	DTCTMK	Fraction of transfer directly from Animal Consumption to Milk.
		OUTPUT VARIABLES	
43	(output)	TIRRG	Time in hours after each irrigation event.
44	(output)	TSOAK	DEPTH/FILTR8

NOTES: The number of pathogens per day entering the pathway will default to APRATE*ASCRS if no value is specified for ASCIN. If a value is specified for ASCIN, it will override the APRATE *ASCRS value.

Whenever three default values are specified for any variable in the list above, the order is salmonellae, ascaris, poliovirus pathogen types. The appropriate default value will be selected to agree with the pathogen type being considered in a particular run.

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TABLE 12b. (concluded)

NOTES (Concluded):

All units of measure are in kilograms, degrees Celsius, or hours unless otherwise stated.

Variables labeled "output" are for internal computations and are not available to the user as input.

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d. For convenience, the pasture is assumed to be 1 hectare in size. This area is large enough to support 12 cows (46) which take their entire intake of food from the forage crop growing in the pasture.

e. The cows are assumed to be a diary herd but a slaughter option has been provided to evaluate pathogen transfer to meat. Each cow consumes 7 kilograms dry weight of forage each day (65). Six percent of the cow's total consumption is crop-associated sludge (17). In addition, each cow is assumed to ingest 200 to 400 kilograms of soil each year or approximately 2 percent of its total diet on a wet weight basis (38). This amounts to 1.1 kilograms per animal per day. These assumptions were used in setting the default values for variables FORAG, SCNSMP, and FSLDGE. Please note that these variables have been set to account for all 12 cows. If the user intends to specify variable values in this pathway, each variable description should be read carefully to determine whether one or 12 cows is accounted for in the variable.

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f. Each cow will add 10 kilograms of manure at 80 percent moisture (60, 58) to the pasture each day. This addition will occur for all 12 cows at one time to simplify the bookkeeping on manure process functions. Manure is assumed to dry at a rate which is based on sludge evaporation. The sludge evaporation rate depends on the clear water evaporation rate for a particular area (10).

g. Salmonella infections in cattle can be systemic (13). Transfers of pathogens directly from the cow to milk and meat are included in the pathway (TA1415 and TA1413, respectively). Because infections of adult cattle are usually nonsymptomatic and localized in the mesenteric lymph nodes (5), default values for the fraction of transfer directly to milk and meat (variables DTCTMK and DTCTMT, respectively) are zero for all pathogens. Infections in cattle are assumed to occur whenever the total consumption of salmonella exceeds 1×10^9 cells per day. In the event of infection, the number excreted per cow per day in manure is increased to 1×10^{12}. Cows cannot be infected by poliovirus or ascaris ova (ascaris in this model always refers to *Ascaris lumbricoides*). Both are assumed to be unaffected by herbivore digestion and to be excreted in the same numbers as ingested. Milk and meat can be contaminated by contact with manure. All three pathogens can be transferred by this route.

h. The user must decide before each pathway run if the cattle grazing the sludge-fertilized pasture are to be a diary herd and milked or are to be a beef herd and slaughtered for meat. If the diary option (this is the default condition) is selected, cows are milked twice a day at 12-hour intervals. Each cow will deliver 15 liters of milk at each milking (65). The milk is stored at 4°C regardless of the ambient temperature selected for

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a model run. The total growth of salmonella in milk is limited to 1 x 10^{12} per milliliter.

i. If the beef herd option is selected by setting the variable COW to -1., a fraction of the manure which contacts the hide will be transferred to meat during slaughter (91). Each cow yields 270 kilograms of meat (53).

j. At the time of application, sludge is chain-harrowed to distribute it evenly over the pasture. A fraction of the applied sludge is knocked to the surface soil, while a fraction clings to crop surfaces. The user may specify this distribution through the variable ASLSUR. Surface soil is defined as the first 10 centimeters of soil. This zone is affected by changing temperatures and dries after each irrigation. Below the surface soil is the subsurface soil which extends from 10 to 80 centimeters. The depth of the zone was defined to include that soil area from which 90 percent of the water requirements of a forage crop are met (6). The subsurface soil layer is at constant temperature and moisture. Pathogens enter the zone with percolating water or during sludge application by the injection method. Because injection places sludge 20 centimeters (8 inches) below the soil surface, pathogens are distributed in the subsurface soil during the application when this option is active.

k. Default values for soil factors describe a sandy loam soil. The water infiltration rate (26, 33) and water holding capacity of the soil (80) are functions of soil type and determine the duration of several compartments. Values used in the transfer of pathogens from the surface to subsurface soil zones were based upon the ability of sandy loam soils to filter and adsorb particles of different sizes carrying different charges (4, 89).

l. The pasture is irrigated initially by sludge application and then with irrigation water at 7-day intervals (6). During spray or spread/flow application of liquid sludge and during periodic irrigation, the pasture is assumed to be flooded to a uniform depth. The water then infiltrates the soil at a uniform rate. Injected sludge will infiltrate the soil below injection depth as if the soil was uniformly flooded at that depth. The default depth of irrigation is calculated to allow infiltration of water only 60 to 90 centimeters below the surface (6), precluding transfer to groundwater and exhibiting good irrigation management. The pasture will be at field capacity after irrigation and the upper 10 centimeters of soil will dry out at a rate calculated for sandy loam soils in the Southwest (68). The area of the field and the irrigation regime should allow production of 7 to 10 tons of alfalfa (or similar forage) per year (3).

m. Irrigation water may be pumped from groundwater influenced by prior irrigation, may be from the diversion of surface flows, or

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may be a combination of water from both sources. Variables are included in the pathway which indicate the dilution factor (GNDIL) of pathogens present in groundwater and the fraction of the total irrigation from this source (FRGIR). Also, the number of pathogens from an external source (EXTRN) can be specified. Manipulation of this variable can simulate weekly surface applications of liquid sludge by inputting a number of pathogens equal to an application of sludge while zeroing the contribution from groundwater.

n. An optional rain is included in the pathway. If requested, the rain will produce surface runoff which removes a fraction of surface-soil-associated pathogens. The values incorporated in the model for intensity and duration of rainfall result in 1/2 inch of rain falling on the pasture in 24 hours. This produces a moderate runoff calculated as one-fourth the peak discharge for a sandy loam soil covered by grass (14).

o. Particulates generated during sludge application by spray irrigation and by the milling of cows in the pasture are assumed to be at a level of 15 milligrams of sludge and/or soil per cubic meter of air in the area of the pasture and to a height of 10 meters.

Compartment Descriptions

Compartment 1, APPLICATION --

Liquid sludge is applied to a 1-hectare pasture by one of three methods. The sludge may be sprayed on (APMETH = -1.), injected 8 inches beneath the surface (APMETH = 0.0), or spread across the field by either a manure spreader or by flow type irrigation (APMETH = +1.). The user must choose one method of application for each run of the model. Each involves a different initial distribution of sludge and pathogens between Compartment 3, PARTICULATES; Compartments 8 and 9, SOIL SURFACE and CROP SURFACE (by way of Compartment 5, INCORPORATION); and Compartment 11, SUBSURFACE SOIL. When liquid sludge is sprayed on, PARTICULATES are generated and the sludge is incorporated into the SOIL SURFACE and contacts CROP SURFACE. When liquid sludge is injected, PARTICULATES are not generated and the sludge bypasses the SOIL SURFACE and is incorporated directly into the SUBSURFACE SOIL. When liquid sludge is spread or flowed on (spread/flow is considered as a single application method) no PARTICULATES are generated and the sludge is incorporated into the SOIL SURFACE and contacts CROP SURFACE. Regardless of which application method is chosen, RESIDUE is left on application equipment at the end of activities.

The model controls the initial transfers from APPLICATION to other compartments by the use of paired variables. The weight of sludge transferred by TAU13 to PARTICULATES is determined by WPAR3A when APMETH = -1. and by WPAR3B when APMETH = 1. or 0.0. Similarly, the fraction of input pathogens transferred to SUBSURFACE SOIL (and immediately incorporated) by TAU111 is determined by FSSURA when APMETH = 0.0 but by FSSURB when APMETH = -1. or +1. The pathogens not transferred by TAU111 are transferred to

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Compartment 5, INCORPORATION, and then to SOIL SURFACE and CROP SURFACE when the pasture is harrowed.

This compartment has a 24-hour duration to simulate the time necessary for a pasture to dry out after surface application of liquid sludge before INCORPORATION (harrowing) can proceed. Process functions provided are those for pathogens in liquid sludge. Injected sludge and its pathogens are not affected by these process functions since TAU111 occurs early in the pathway, transferring these pathogens to SUBSURFACE SOIL.

Time of first transfer into compartment - Start of pathway.

Time of last transfer out of compartment - 24 hours into pathway.

Process function - RH01
Activated: At the start of the pathway
Duration: 24 hours.
Rates:

Rates:	Salmonella:	0.13*N(1)/hour, for $20 < TEMP < 45$ to an upper limit of 1×10^9 salmonella per kilogram (dry weight) of sludge applied. The growth of salmonella in liquid sludge is an estimate based upon one-half the rate of growth for E. coli in sterile sludge (76). -3.45*N(1)/hour, for $TEMP \geq 45$ (8, 93). 0.0*N(1)/hour, for $TEMP < 20$.
	Ascaris:	-0.00041*N(1)/hour, for $20 < TEMP < 40$. (22, 31, 32, 70). -1.535*N(1)/hour, for $TEMP \geq 40$. (7, 54). 0.0*N(1)/hour, for $TEMP < 20$.
	Poliovirus:	-0.01*N(1)/hour, for $TEMP < 45$. (44, 87). -0.38*N(1)/hour, for $TEMP \geq 45$. (88, 97).

Transfers into compartment -
TAU01 = ASCIN, Transfer occurs at the beginning of the pathway.

Transfers out of compartment -
TAU12 = (WTRES2/(APRATE - WPAR3_))*N(1), Transfer occurs 8 hours into the pathway.
TAU13 = (WPAR3_/APRATE)*N(1), Transfer occurs 1 hour into the pathway.
TAU15 = N(1), Transfer occurs 24 hours into the pathway.
TAU111 = FSSUR_*N(1), Transfer occurs 9 hours into the pathway.

Compartment 2, RESIDUE ON EQUIPMENT --

RESIDUE is left on equipment at the end of the APPLICATION compartment. The amount is determined by the variable WTRES2. The default value for this variable is an estimate. The material in RESIDUE compartments is

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assumed to dry out rapidly. The process functions assigned to this and other RESIDUE compartments reflect the effects of desiccation on the model pathogens.

Time of first transfer into compartment - 8 hours into pathway.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RHO2
Activated: 8 hours into pathway.
Duration: Until all pathogens are depleted or the pathway ends.
Rates:
Salmonella: 0.13*N(2)/hour, for % solids of sludge < 70 and $20 \le \text{TEMP} \le 40$ to an upper limit of 1×10^9 per kilogram solids. This growth rate is one-half the rate of E.coli in sterile sludge. (76)
-0.05*N(2)/hour, for $70 <$ % solids < 80 and TEMP < 40. (8)
-3.45*N(2)/hour % solids < 80 and TEMP ≥ 40. (8, 93)
-0.46*N(2)/hour, for % solids ≥ 80. (8)
0.0*N(2)/hour, for % solids < 80 and TEMP < 20.
Ascaris: -0.0012*N(2)/hour, for TEMP < 40 and % solids < 95. (40)
-1.535*N(2)/hour, for $40 \le \text{TEMP} \le 50$ and % solids < 95. (7, 78)
-0.25*N(2)/hour, for % solids ≥ 95. (22 40, 74)
Poliovirus: -0.01*N(2)/hour, for % solids < 65 and TEMP < 45. (44, 87)
-0.38*N(2)/hour, for TEMP ≥ 45. (88, 97)
-0.02*N(2)/hour, for % solids ≥ 65 and TEMP < 45. (87)

Transfers into compartment -
TAU12 = (WTRES2/(APRATE-WPAR3_))*N(1), Transfer occurs 8 hours into pathway.

Transfers out of compartment - None.

Compartment 3, PARTICULATES --

The activities described for Compartment 1 can generate airborne sludge droplets or PARTICULATES when APMETH = -1. It is assumed in all PARTICULATE compartments that the airborne material is generated at the start of activities in the compartment from which the transfer to PARTICULATES is made, in this case Compartment 1 - APPLICATION, and that the airborne material and its associated pathogens remain at the initial concentration until the generating activity ceases. The process functions in all PARTICULATES compartments are delayed to allow for maximum inhalation of pathogens during generation activities.

The user may specify the amount of sludge being transferred to this compartment by assigning a value to either WPAR3A or WPAR3B. There are three compartments described by the title PARTICULATES in this pathway: Compartment 3, Compartment 4, and Compartment 7. To avoid confusion in this and other pathways a naming system was used in which the "weight transferred to PARTICULATES" is abbreviated "WTPAR or WPAR" and the number of the compartment concerned is appended. The shorter abbreviation is used when more information is needed to describe the variable. In this compartment, the amount of sludge which would become airborne as PARTICULATES depends on the application method. Only spray irrigation should lead to particulate generation (APMETH = -1.). Neither spread/flow irrigation nor injection (APMETH = +1. and 0.0, respectively) should result in airborne sludge droplets. Therefore, two variables are provided, WPAR3A for APMETH = -1. and WPAR3B for APMETH = +1. and 0.0. A similar system is used to identify RESIDUE transfer variables. Thus, WTPAR6 is the weight of sludge transferred to PARTICULATES in Compartment 6 and WPAR3A is the weight of sludge transferred in Compartment 3 when APMETH = -1.

The default value assigned WPAR3A was determined by assuming that PARTICULATES are generated to a level of 15 mg/m^3 in a volume extending 10 meters over the 1-hectare pasture. The concentration of particules and the height of the volume considered are the same in all PARTICULATES compartments but the area under the cloud differs between pathways.

The process functions for PARTICULATES are the same as for RESIDUE and reflect the effects of rapid desiccation of the airborne material and the pathogens associated with it.

Time of first transfer into compartment - 1 hour into pathway.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RHO3
    Activated: 8 hours into pathway.
    Duration: Until all pathogens are depleted or the pathway ends.
    Rates: Salmonella: -0.46*N(3)/hour. (8)
        Ascaris: -0.25*N(3)/hour. (22, 40, 74)
        Poliovirus: -0.38*N(3)/hour. (88, 97)

Transfers into compartment -
    TAU13 = (WPAR3_/APRATE)*N(1), Transfer occurs 1 hour into pathway.

Transfers out of compartment - None.

Compartment 4, RESIDUE ON EQUIPMENT --

RESIDUE is left on equipment at the end of the INCORPORATION compartment. The amount is determined by the variables WRES4A and B. The amount of residue left on equipment following INCORPORATION depends on the method of sludge application chosen. WRES4A is the variable used when the liquid sludge is injected (APMETH = 0.0), while WRES4B is the variable used when sludge is applied to the surface. The default values for these variables are estimates. The material in RESIDUE compartments is assumed to dry out rapidly. The process functions assigned to this and other RESIDUE compartments reflect the effects of desiccation on the model pathogens.

Time of first transfer into compartment - 28 hours into pathway.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RH04

Activated: 28 hours into pathway.

Duration: Until all pathogens are depleted or the pathway ends.

Rates:

Salmonella:	-0.46 * N(4)/hour. (8) The inactivation of residue-associated salmonella is assumed to occur at the rate for salmonella in drying sludge at greater than 80 percent solids.
Ascaris:	-0.25*N(4)/hour. (22 40, 74)
Poliovirus:	-0.38*N(4)/hour. (88, 97)

Transfers into compartment -

TAU54 = (WRES4_/(APRATE-WTPAR6))*N(5), Transfer occurs 28 hours into pathway.

Transfers out of compartment - None.

Compartment 5, INCORPORATION --

In Compartment 1, sludge is applied to a 1-hectare pasture planted in a forage crop that is being actively grazed by 12 cows. The amount is determined by the variable APRATE and the pathogen population by the variable ASCRS. The sludge-covered pasture is then chain-harrowed, an operation which spreads the sludge evenly over the whole pasture and knocks some of it from the forage-crop surface to the soil surface. At the end of INCORPORATION the applied sludge is distributed between Compartment 8, SOIL SURFACE, and Compartment 9, CROP SURFACE. The user may determine the division of sludge between these two compartments by specifying a value for the variable TINCSR. This variable specifies what percentage of the total pathogen population in applied sludge reaches the SOIL SURFACE. The remaining sludge is assumed to cling to the forage CROP SURFACE. The default value for TINCSR is an unsupported estimate.

There are four transfers out of this compartment. During harrowing operations, dust is generated. This is simulated by a transfer of sludge-associated pathogens by TAU56 to Compartment 6, PARTICULATES. The amount of sludge transferred when the default value of WTPAR6 is used was calculated by assuming the production of 15 milligrams of particulates per cubic meter in a 10-meter high volume above the entire 1-hectare pasture. This weight of sludge is divided by the total weight of sludge in Compartment 5 and is then multiplied by the number of pathogens in Compartment 5 to determine the number of pathogens transferred to PARTICULATES. This transfer occurs 26 hours into the pathway.

Sludge adheres to harrowing equipment. A weight of sludge specified by variable WRES4A or B is transferred to Compartment 4, RESIDUE, by TAU54. The amount of residue left on equipment depends on the method of sludge application chosen. WTRES4A is the variable used when the sludge is injected (APMETH = 0.0), while WRES4B is the variable used when the sludge is applied on the surface. The number of pathogens associated with the transferred sludge is calculated in the same manner as the particulate-associated pathogens above. This transfer occurs 28 hours into the pathway.

At the end of activities for this compartment the transfers are made to Compartment 8, SOIL SURFACE, and to Compartment 9, CROP SURFACE, by TAU58 and TAU59, respectively.

Time of first transfer into compartment - 24 hours into pathway

Time of last transfer out of compartment - 28 hours into pathway.

Process function - RHO5
Activated: 24 hours into pathway
Duration: 4 hours.
Rates:
Salmonella: 0.13*N(5)/hour, for 20 < TEMP < 45 to an upper limit of 1 x 10^9 salmonella per gram dry weight of soil. Growth of salmonella in the liquid sludge/soil mixture is an estimate based on one-half the rate of growth for E.coli in sterile sludge. (76)
-3.45*N(5)/hour, for TEMP ≥ 45. (8, 93)
0.0*N(5)/hour, for TEMP ≤ 20.
Ascaris: -0.00041*N(5)/hour, for 20 < TEMP < 40. (22, 31, 32, 70)
-1.535*N(5)/hour, for TEMP ≥ 40. (7, 78)
0.0*N(5)/hour, for TEMP ≤ 20.
Poliovirus: -0.01*N(5)/hour, for TEMP < 45. (44, 87)
-0.38*N(5)/hour, for TEMP ≥ 45. (88, 97)

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Transfers into compartment -
TAU15 = N(1), Transfer occurs 24 hours into the pathway.

Transfer out of compartment -
TAU54 = (WRES4_/(APRATE-WTPAR6)*N(5), Transfer occurs 28 hours into pathway.
TAU56 = (WTPAR6/APRATE)*N(5), Transfer occurs 26 hours into pathway.
TAU58 = TINCSR*N(5), Transfer occurs at 27 hours into pathway.
TAU59 = (1. - TINCSR)*N(5), Transfer occurs at 27 hours into pathway.

Compartment 6, PARTICULATES --

The activities described for Compartment 5 will generate airborne dust or PARTICULATES. It is assumed in all PARTICULATE compartments that the dust is generated at the start of activities in the compartment from which the transfer to PARTICULATES is made, in this case Compartment 5, INCORPORATION, and that the dust and its associated pathogens remain at the initial concentration until the generating activity ceases. The process functions in all PARTICULATES compartments are delayed to allow for maximum inhalation of pathogens during generation activities.

The default value assigned WTPAR6 was determined by assuming that PARTICULATES are generated to a level of $15 mg/m^3$ in a volume extending 10 meters over the 1-hectare pasture. The concentration of particules and the height of the volume considered are the same in all PARTICULATES compartments but the area under the dust cloud differs between pathways.

The process functions for PARTICULATES are the same as for RESIDUE and reflect the effects of rapid desiccation of the airborne material and the pathogens associated with it.

Time of first transfer into compartment - 26 hours into pathway.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RHO6
Activated: 30 hours into pathway.
Duration: Until all pathogens are depleted or the pathway ends.
Rates:
Salmonella: -0.46*N(6)/hour. (8)
Ascaris: -0.25*N(6)/hour. (22, 40, 74)
Poliovirus: -0.38*N(6)/hour. (88, 97)

Transfers into compartment -
TAU56 = (WTPAR6/APRATE)*N(5), Transfer occurs 26 hours into pathway.

Transfers out of compartment - None.

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Compartment 7, PARTICULATES --

The PARTICULATES generated in this compartment represent the dust raised by normal winds and the milling of cattle in the pasture. The dust is blown up from the SOIL SURFACE as simulated by transfer TAU87. The amount of sludge-amended soil involved is specified by assigning a value to WTPAR7. The default value for this variable assumes that 15 milligrams of dust are generated for each cubic meter of air in a 10-meter high volume above the 1-hectare pasture. PARTICULATES are generated every day for the duration of the pathway. Process functions are delayed to allow for maximum exposure by workers who might enter the field.

Time of first transfer into compartment - 50 hours into pathway.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RHO7

Acitvated: 54 hours into the pathway.

Duration: Until all pathogens are depleted or the pathway ends.

Rates:	Salmonella:	-0.46*N(7)/hour.	(8)
	Ascaris:	-0.25*N(7)/hour.	(22, 40, 74)
	Poliovirus:	-0.38*N(7)/hour.	(88, 97)

Transfers into compartment -

TAU87 = (WTPAR7/APRATE*TINCSR))*N(8), Transfer occurs 50 hours into the pathway and then every 24 hours.

Transfers out of compartment - None.

Compartment 8, SOIL SURFACE --

In a pasture with a standing forage, a fraction of the sludge applied would land on the soil surface. Even through the pasture is not plowed, the SOIL SURFACE includes the upper 10 centimeters of the soil profile. This layer is subjected to weekly changes in moisture as a result of irrigation. It is at field capacity (20 percent weight/weight) after each irrigation and dries linearly to the wilting point (4 percent weight/weight) between irrigations. Pathogen process functions are tied to the irrigation cycle. The rate of growth or inactivation of pathogens is dependent on the ambient temperature of the environment and on the available water. The ambient temperature is set by the variable TEMP and is constant throughout the pathway. The available water is a function of the time elapsed since the last irrigation.

Sludge fertilizer and pathogens are first transferred into this compartment from the INCORPORATION compartment by TAU58. As the pathway progresses there are several other transfers. At irrigation, water from Compartment 20, IRRIGATION WATER, is transferred to Compartment 12, SOIL SURFACE WATER. This water then percolates into the soil, transferring pathogens to SOIL SURFACE by TAU128. The pathogens involved in this transfer may be either soil pathogens which become suspended in the water during

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irrigation, a phenomenon simulated by TAU128,or may be pathogens introduced with the irrigation water itself. In a similar manner, after pathogens have been transferred to CROP SURFACE, some will be returned to SOIL SURFACE when gravity and wind cause dust on the crop to fall to the ground (TAU98). Pathogens also enter this compartment when the grazing cattle deposit manure on the ground; an event which occurs once each day and is shown by TAU168.

There is one other way for pathogens to enter this compartment. The user may place an initial pathogen population in any pathway compartment by specifying the compartment number and the desired population in the POPL variable of the $ARGS name list. The mechanism for handling variable specification is fully described in the user's manual for the program (Appendix A). Specifying an initial pathogen population allows the user to examine the effects of several sludge applications. The final compartment populations of one model run would be input as initial populations in the next run. Environmental conditions may be unique for each run, or standard default values may be used.

Pathogens are transferred from this compartment into Compartment 7, PARTICULATES, by TAU87; Compartment 11, SUBSURFACE SOIL, by TAU811; Compartment 9, CROP SURFACE, by TAU89; Compartment 14, ANIMAL CONSUMPTION, by TAU814; and to Compartment 10, SURFACE RUNOFF, by TAU810. PARTICULATES are generated daily by wind and milling cattle. The transfer from SOIL SURFACE to SUBSURFACE SOIL occurs after each irrigation when irrigation water percolates below the 10-centimeters mark which separates SOIL SURFACE from SUBSURFACE SOIL. The time of this transfer is controlled by the infiltration rate of SOIL SURFACE WATER, a parameter the user may specify in the variable FILTR8. The infiltrating water carries pathogens with it. The fraction of the total population in SOIL SURFACE transferred by percolating water to SUBSURFACE SOIL is specified in the variable SSTSSS. The default values for this variable are estimates that take into account the size and soil-binding capabilities of each pathogen.

Pathogens associated with SOIL SURFACE are suspended in irrigation water while it is lying on the surface of the pasture and is considered to be in Compartment 12, SOIL SURFACE WATER. This transfer occurs at the beginning of each irrigation cycle. The fraction of total SOIL SURFACE pathogens suspended in SOIL SURFACE WATER is determined by the variable SSTSSW. These pathogens and any introduced from IRRIGATION WATER are transferred to SOIL SURFACE when the irrigation water percolates into the soil.

A portion of the dust raised by grazing cattle is assumed to contact and then cling to the surface of the forage crop. This transfer of soil and soil-associated pathogens to CROP SURFACE occurs once each day. The weight of soil involved in the transfer is specified in the variable SSTCS. As explained in item e of the General Considerations for this pathway, cows consume soil as well as forage when grazing. The amount of soil transferred each day to ANIMAL CONSUMPTION is specified by the variable SCNSMP.

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The transfer to SURFACE RUNOFF simulates the effects of a rain and occurs at TRAIN. The rain which produces runoff is an arbitrary event which does not occur under default conditions. The user must set TRAIN to a positive number for rain to occur. The number will equal the time in hours when the rain occurs. The user may also control the number of pathogens washed from the SOIL SURFACE and removed from the pathway by TAU810 by specifying the value of FRAIN.

Time of first transfer into compartment - 27 hours into pathway.

Time of last transfer out of compartment - End of pathway.

Process function - RH08
Activated: 27 hours into pathway.
Duration: Until the end of the pathway.
Rates:
Salmonella:
0.070*N(8)/hour, for 20 ≤ TEMP < and 0 < TIRRG ≤ 3.5 days. The growth of salmonella is assumed to occur at one-half the rate for *E.coli* in the sterile compost. (62)
-0.012*N(8)/hour, for 20 ≤ TEMP < and 3.5 < TIRRG ≤ 5.5 days. (23, 72, 73)
-0.46*N(5)/hour, for 20 ≤ TEMP < 45 and 5.5 < TIRRG ≤ 7 days. (8)
-3.45*N(5)/hour, for TEMP ≥ 45 and any time. (8, 93)
0.0*N(8)/hour, for TEMP < 20 and any time. No changes in pathogen population are assumed for temperatures less then 20°C.
Ascaris:
-0.0005*N(8)/hour, for TEMP < 40 and 8 hours < TIRRG ≤ 5.5 days. (83)
-1.54*N(8)/hour, for 40 ≤ TEMP ≤ 50 and 8 hours < TIRRG ≤ 5.5 days. (7, 78)
-0.25*N(8)/hour, for TIRRG > 5.5 days and any temperature. (22, 40, 74)
0.0*N(8)/hour, for TIRRG < 8 hours and any temperature.
Poliovirus:
-0.005*N(8)/hour, for 15 < TEMP < 45 and 8 hours < TIRRG ≤ 6.5 days. (27, 96)
-0.027*N(8)/hour, for TEMP < 45 and TIRRG > 6.5 days. (87, 96)
-0.38*N(8)/hour, for TEMP ≥ 45 and any time. (88, 97)
-0.00087*N(8)/hour, for TEMP < 15 and 8 hours < TIRRG < 6.5 days. (96)
0.0*N(8)/hour, for TEMP < 45 and TIRRG < 8 hours.

Transfers into compartment -
TAU58 = TINCSR*N(5), Transfer occurs 27 hours into pathway.

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TAU98 = (CSTSS/24.)*N(9), Transfer occurs hourly after 27 hours into pathway.

TAU128 = (1. - SSWTCS)*N(12), Transfer occurs after each irrigation at TIRRG + (DEPTH/FILTR8).

TAU168 = MTSS*N(16), Transfer occurs every 24-hours from 186 hours into pathway.

Transfers out of compartment -

TAU87 = (WTPAR7/(APRATE * TINCSR))*N(8), Transfer occurs at 50 hours into the pathway and then every 24 hours.

TAU89 = SSTCS*N(8), Transfer occurs at 24 hour intervals from 50 hours.

TAU810 = FRAIN*N(8), Transfer occurs if a rain is specified and then at TRAIN.

TAU811 = SSTSSS*N(8), Transfer occurs after each irrigation at (DEPTH/FILTR8) + 1 hour.

TAU812 = SSTSSW*N(8), Transfer occurs at each irrigation.

TAU914 = (SCNSMP/APRATE)*N(8), Transfer occurs at 24-hour intervals from 54 hours.

Compartment 9, CROP SURFACE --

In a pasture with a standing crop, a fraction of the sludge applied would land on the CROP SURFACE, a transfer shown by TAU59. The user can control the distribution of sludge between Compartment 8, SOIL SURFACE, and Compartment 9 by specifying the value of TINCSR. As the pathway progresses there are several other transfers into this compartment. The cattle grazing the pasture stir up dust from the SOIL SURFACE. Some of the dust (an amount specified by SSTCS) will cling to the CROP SURFACE. This transfer, TAU89, occurs daily. The grazing cows also contribute MANURE to the pasture, some of which lands on the CROP SURFACE and may carry a pathogen load. TAU169, the transfer of manure-associated pathogens, occurs daily. The crop is washed by irrigation water once each week. As the water soaks into the soil a fraction of the pathogens in Compartment 12, SOIL SURFACE WATER, are transferred by TAU129 to CROP SURFACE. This fraction is controlled by the variable SSWTCS.

It is assumed that workers operate the machinery used to chain-harrow the pasture and that someone checks on irrigation each week. Workers would come into contact with the CROP SURFACE and remove some crop-associated pathogens directly from the pasture by TAU921.

Pathogens can be transferred from this compartment back to Compartment 8, SOIL SURFACE, as dust and leaves fall to the ground. TAU98 is a continuing transfer throughout the pathway, with a fraction of the total population of Compartment 9 (SCTSS) transferred each hour. During irrigation, a fraction of the total population (variable CSTSSW is calculated to be that part associated with water-covered foliage when the irrigation depth is 6 inches) is suspended in SOIL SURFACE WATER. Pathogens are also transferred from this compartment when cows consume the crop.

The user may specify the dry weight of forage consumed by the 12 grazing cows each day by assigning a value to the variable FORAG. The

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default value is an average consumption for a lactating dairy cow. The user may also specify how much of the forage is sludge by defining FSLDGE. These factors are divided by the weight of sludge in the compartment to determine the total weight of sludge consumed and thus the pathogen population consumed. While cows eat continuously, the transfer from CROP SURFACE to ANIMAL CONSUMPTION, TAU914, is made once a day.

Time of first transfer into compartment - 27 hours into pathway.

Time of last transfer out of compartment - End of pathway.

Process function - RH09
Activated: 27 hours into pathway.
Duration: Until the end of the pathway.
Rates: Salmonella: -0.096*N(9)/hour. (72, 73)
Ascaris: -1.54*N(9)/hour. (7, 78)
Poliovirus: -0.069*N(9)/hour. (49)

Transfers into compartment -
TAU59 = (1. - TINCSR)*N(5), Transfer occurs 27 hours into pathway.
TAU89 = SSTCS*N(8), Transfer occurs at 24-hour intervals from 50 hours into pathway.
TAU129 = SSWTCS*N(12), Transfer occurs after each irrigation at TIRRRG + (DEPTH/FILTR8).
TAU169 = (1. - (TMTSS + TMTH + TMTU))*N(16), Transfer occurs at 24-hour intervals from 54 hours into pathway.

Transfers out of compartment -
TAU98 = (CSTSS/24.)*N(9), Transfer occurs hourly from 27 hours into the pathway.
TAU912 = (STSSW*N(9), Transfer occurs at each irrigation.
TAU914 = (FORAG * FSLDGE)*N(9), Transfer occurs at 24-hour intervals from 54 hours into the pathway.
TAU921 = CSTDC*N(9), Transfer occurs at 7-day intervals from 185 hours and once at 29 hours.

Compartment 10, SURFACE RUNOFF --

Pathogens are transferred into this compartment from Compartment 8, SOIL SURFACE, only if a rain occurs. The compartment exists to show that the transfer occurs and to keep track of the pathogen population removed. No process functions have been defined for this compartment. It is beyond the scope of this model to follow pathogens washed from a field by storm runoff.

Time of first transfer into compartment - TRAIN.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

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Process function - RHO10
Activated: TRAIN
Duration: Until all pathogens are depleted or the pathway ends.
Rates: Salmonella: 0.0*N(10)/hour.
Ascaris: 0.0*N(10)/hour.
Poliovirus: 0.0*N(10)/hour.

Transfers into compartment -
TAU810 = FRAIN*N(8), Transfer occurs at TRAIN.

Transfers out of compartment - None.

Compartment 11, SUBSURFACE SOIL --

This compartment represents the soil from 10 to 80 centimeters below the surface. This SUBSURFACE SOIL is at constant moisture (field capacity, 20 percent weight/weight) and temperature (15°C). When the injection method of liquid sludge application is chosen (APMETH = 0.0), the sludge and its associated pathogens are transferred directly into this compartment during APPLICATION by TAU111. A pair of variables, FSSURA and FSSURB, determine the fraction of ASCIN which is transferred directly to SUBSURFACE SOIL. Pathogens from the sludge and manure fertilized upper 10 centimeters of soil are transferred into this compartment with percolating irrigation water. The fraction of the total SOIL SURFACE (Compartment 8) pathogen population transferred is determined by the variable SSTSSS. The time of the transfer by TAU811 is controlled by the depth of irrigation water which must soak in (DEPTH) and the rate of water infiltration (FILTR8), but the transfer occurs after each irrigation.

Pathogens may be transferred to Compartment 18, GROUNDWATER, by TAU118. The variable SSSTGW, which specifies the fraction of total SUBSURFACE SOIL pathogens transferred, is set to zero under default conditions. The 6 centimeters of applied irrigation water specified by default values would only penetrate to 60 centimeters, precluding transfer to GROUNDWATER. The user should specify a value for SSSTGW if DEPTH is set to more than 6 centimeters.

Time of first transfer into compartment - 9 hours into pathway.

Time of last transfer out of compartment - End of pathway.

Process function - RHO11
Activated: 9 hours into pathway.
Duration: Until the pathway ends.
Rates: Salmonella: -0.012*N(11)/hour. (23, 72, 73)
Ascaris: -0.000053*N(11)/hour. (83)
Poliovirus: -0.0049*N(11)/hour. (27, 96)

Transfers into compartment -
TAU811 = SSTSSS*N(8), Transfers occurs after each irrigation at TIRRG + (DEPTH/FILTR8) + (10 centimeters/FILTR8).

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Transfers out of compartment -
TAU111 = FSSUR_*N(1), Transfer occurs 9 hours into the pathway.
TA1118 = SSSTGW*N(11), Transfer occurs after each irrigation at TIRRG + (DEPTH/FILTR8) + (80 centimeters/FILTR8) and also after rain at TRAIN + (DEPTH/FILTR8) + (80 centimeters/FILTR8).

Compartment 12, SOIL SURFACE WATER --

Irrigation in this model involves flooding the pasture with water or sludge to a uniform depth (specified by the variable DEPTH) and then allowing the water to infiltrate the soil at a constant rate (specified by the variable FILTR8). The water transfers into SOIL SURFACE WATER from Compartment 20, IRRIGATION WATER, by TA2012 and may carry with it a pathogen load. Pathogens in SOIL SURFACE and on the CROP SURFACE will become suspended in the overlying water. These transfers from Compartment 8 and Compartment 9, respectively, will occur for each weekly irrigation (TIRRG) starting 173 hours into the pathway.

The variable TIRRG is used in several ways in the model. Its value is incremented by 168 hours each time it is used so that irrigation occurs at weekly intervals after the first irrigation. The variable is also used in the process functions for Compartment 8 to keep track of the time elapsed since the last irrigation.

Pathogens transfer back to Compartment 8, SOIL SURFACE, and Compartment 9, CROP SURFACE, when the irrigation water soaks into the soil. While this would normally be a gradual process, TAU128 and TAU129 occur at the end of irrigation as a single transfer to each compartment.

Time of first transfer into compartment - 173 hours into pathway (at the first irrigation).

Time of last transfer out of compartment - After the last irrigation at 577 + (DEPTH/FILTR8) hours.

Process function - RH012
Activated: TIRRG (with each irrigation).
Duration: (DEPTH/FILTR8).
Rates: Salmonella: 0.23*N(12)/hour. A 3-hour generation time is assumed for growth of salmonella suspended in irrigation water.
Ascaris: 0.0*N(12)/hour.
Poliovirus: 0.0*N(12)/hour. No change is assumed for ascaris and poliovirus suspended in irrigation water.

Transfers into compartment -
TAU812 = SSTSSW*N(8), Transfer occurs at each weekly irrigation, starting 173 hours into pathway.
TAU912 = CSTSSW*N(9), Transfer occurs at each weekly irrigation, starting 173 hours into pathway.
TA2012 = N(20), Transfer occurs at each weekly irrigation, starting 173 hours into pathway.

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Transfers out of compartment -

TAU128 = (1. - SSWTCS)*N(12), Transfer occurs after each irrigation at TIRRG + DEPTH/FILTR8).

TAU129 = SSWTCS*N(12), Transfer occurs after each irrigation at TIRRG + (DEPTH/FILTR8).

Compartment 13, MEAT --

If the beef cow option is chosen (the variable COW is set by the user to -1.), the cows grazing the pasture will be slaughtered at TSLOTR. This variable must be set by the user to be a time less than 30 days (the time the pathway ends under default values). Slaughter will occur when pathogen levels in the cows are highest on the day assigned to TSLOTR. At slaughter, the cows become 3240 kilograms of MEAT (12 cows x 270 kilograms per cow). Pathogens can be transferred to MEAT by two routes. Salmonella can infect a cow. TA1413 simulates the direct transfer of pathogens from ANIMAL CONSUMPTION, Compartment 14, to MEAT. The default value for DTCTMT is zero since no data could be found quantifying the contamination of meat from a systemic salmonella infection and neither ascaris nor poliovirus should transfer from the gut of the cow. The user can assign a value to DTCTMT if contamination of MEAT by a systemic infection is desired. This transfer would occur daily but only for salmonella pathogen type.

When cattle are butchered, the MEAT is often contaminated by enteric bacteria. The model shows this transfer as being between the manure-contaminated HIDE and the MEAT. TA1913 will occur at TSLOTR. Default values for HTM, the fraction of HIDE pathogens transferred to MEAT, are available for all three pathogen types. These are, of course, estimates. MEAT is assumed to be kept at 4°C following slaughter. There are no transfers out of this compartment but the pathogen population is used in meat exposure risk calculations.

Time of first transfer into compartment - 54 hours into the pathway.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathway terminates.

Process function - RH013

Activated: 54 hours into pathway.
Duration: Until the pathway ends.
Rates: Salmonella: 0.76*N(13)/hour to an upper limit of 1×10^9 salmonella per kilogram of meat. Salmonella is allowed to grow at a generation time of 6 hours at 4°C.
Ascaris: 0.0*N(13/hour.
Poliovirus: 0.0*N(13)/hour. Poliovirus and ascaris remain at the level transferred at slaughter.

Transfers into compartment -

TA1413 = DTCTMT*N(14), Transfer occurs 54 hours into the pathway and then at 24-hour intervals.

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TA1913 = HTM*N(19), Transfer occurs at TSLOTR.

Transfers out of compartment - None.

Compartment 14, ANIMAL CONSUMPTION --
Twelve cows are grazing the pasture at the time of sludge application. This compartment represents those cows as they consume the growing pasture crop and digest it. Pathogens can be transferred into this compartment from two sources, CROP SURFACE by TAU914 and SOIL SURFACE by TAU814. No provision is made for possible ingestion of irrigation water during the time when the pasture is flooded. Although grazing is a continuous process, the transfers into this compartment are made once a day as discrete events starting 54 hours into the pathway.

In the absence of data, it was assumed that herbivore digestive processes would not alter ingested pathogen populations. The possibility of infection by salmonella was taken into account. If the total daily transfer of pathogens into the compartment exceeds 1×10^9 salmonella per cow, infection is simulated by increasing the population in the compartment by three orders of magnitude and excreting this larger number in the manure. Transfers TA1415 and TA1413, from ANIMAL CONSUMPTION to MILK and MEAT may also be used to simulate the effects of salmonella infection. While the default values for both DTCTMT and DTCTMK (the variables which specify the fraction of direct transfer of salmonella from ANIMAL CONSUMPTION to MEAT and MILK, respectively) are zero, the user may input values to indicate contamination of foodstuffs as a result of systemic infection.

Materials which are consumed by the cows have a 2-day residence time before being excreted to MANURE by TA1416. One-half of the pathogen population of Compartment 14 is transferred to Compartment 16 each day as a discrete event.

Time of first transfer into compartment - 54 hours into pathway.

Time of last transfer out of compartment - End of pathway.

Process function - RH014
  Activated: 54 hours into pathway.
  Duration: Until the pathway ends.
  Rates: Salmonella: If (TAU814 + TAU914) $\geq 1 \times 10^9$/cow, there is an immediate increase to $(1 \times 10^3$*N(14)). If TAU814 + TAU914 < 1×10^9/ cow, there is no change in the population in this compartment, 0.0*N(10)/hour.
  Ascaris: 0.0*N(10)/hour.
  Poliovirus: 0.0*N(10)/hour.

Transfers into compartment -
  TAU814 = SCNSMP*N(8), Transfer occurs at 24-hour intervals from 54 hours.

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TAU914 = (FORAG*FSLDGE)*N(9), Transfer occurs at 24-hour intervals from 54 hours.

Transfers out of compartment -

TA1413 = DTCTMT*N(14), Transfer occurs at 54 hours into the pathway and then at 24-hour intervals.
TA1415 = DTCTMK*N(14), Transfer occurs at 12-hour intervals from 60 hours.
TA1416 = N(14)/2., Transfer occurs at 24-hour intervals from 66 hours into the pathway.

Compartment 15, MILK --

The cows are milked twice each day when the dairy cow option is chosen (COW = +1.). This is the default condition. The MILK is kept at 4°C for 11 hours but is assumed to be removed from the pathway before the next milking. Pathogens can be transferred to MILK directly from Compartment 14, ANIMAL CONSUMPTION, by TA1415. This transfer will simulate the possible effects of a systemic salmonella infection. The user must supply a value for DTCTMK, the variable which specifies the fraction of Compartment 14 pathogens transferred. The default value for this variable is zero. Neither poliovirus nor ascaris are known to infect cattle and would not pass from the gut.

Pathogens are more readily transferred into milk by dirty utensils and careless handling. In the model these are combined as a transfer from manure-contaminated UDDER, Compartment 17. Transfer TA1715 occurs at each milking. All three pathogens can enter MILK by this route. The default value for UTM is an estimate. There are no transfers out of this compartment but the pathogen population is used in milk-exposure risk calculations.

Time of first transfer into compartment - 60 hours into pathway.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathway terminates.

Process function - RH015

Activated: 72 hours into the pathway.
Duration: 11 hours after each milking.
Rates:
Salmonella: 0.076*N(15)/hour to a limit of 1 x 10^{12} salmonella per milliliter of milk. Salmonella is allowed to grow at a generation time of 6 hours at 4°C.
Ascaris: 0.0*N(15)/hour.
Poliovirus: 0.0*N(15)/hour. Poliovirus and ascaris remain at the level transferred in.

Transfers into compartment -

TA1415 = DTCTMK*N(14), Transfer occurs at 12-hour intervals from 60 hours.

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TA1715 = UTM*N(17), Transfer occurs at 12-hour intervals from 72 hours into pathway.

Transfers out of compartment - None.

Compartment 16, MANURE --

Each day one-half of the pathogen population in Compartment 14, ANIMAL CONSUMPTION, is transferred to MANURE by TA1416. The inactivation of pathogens in MANURE is a function of both the ambient temperature of the pathway (set in the variable TEMP) and the moisture content of the manure. Each day's manure dries separately as shown below in significant calculations.

Depending upon which type of cow is grazing the pasture, a fraction of the deposited MANURE will contact HIDE or UDDER. When the beef cow option is selected (COW = -1.), TA1619 transfers a fraction of the total pathogen population in MANURE (as specified by TMTH) to Compartment 19, HIDE, at the time of deposition. When the dairy cow option is operating (COW = +1.), TA1617 transfers a fraction of the pathogens to Compartment 17, UDDER. These transfers allow indirectly for the contamination of MEAT and MILK.

Regardless of the type of cattle involved, some MANURE lands on the CROP SURFACE and some on the SURFACE SOIL. These transfers are calculated by TAU168 and TAU169, respectively. The variable TMTSS controls the distribution of manure between CROP SURFACE and SURFACE SOIL.

Significant calculations - Drying of manure is based upon an 8 centimeter thick layer of 20 percent solids manure evaporating at 0.7 times the clear water evaporation rate for the Albuquerque, New Mexico area.

Percent solids (PRSOL) = 100 - (-5.33T + 80.0), where T = days after first deposit of manure.

Time of first transfer into compartment - 56 hours into pathway.

Time of last transfer out of compartment - End of pathway.

Process function - RHO16
Activated: 56 hours into pathway.
Duration: Until the pathway ends.
Rates: Salmonella: -0.46*N(16)/hour, for PRSOL ≥ 80. (8)
-3.45*N(16)/hour, for PRSOL ≤ 80 and TEMP > 45. (8, 93)
-0.048*N(16)/hour, for PRSOL < 80 and TEMP < 45. (8)
Ascaris: -0.251*N(16)/hour, for PRSOL ≥ 95. (23, 40, 74)
-1.535*N(16)/hour, for PRSOL < 95 and TEMP > 40. (7, 78)
0.0*N(16)/hour, for PRSOL < 95 and TEMP < 40.

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Poliovirus: -0.384*N(16)/hour, for TEMP ≥ 45. (88, 97)
-0.0192*N(16)/hour, for TEMP < 45 and PRSOL > 65. (87)
-0.014*N(16)/hour, for TEMP < 45 and PRSOL ≤ 65. (44, 87)

Transfers into compartment -
TA1416 = N(14)/2., Transfer occurs at 24-hour intervals from 56 hours into the pathway.

Transfers out of compartment -
TAU168 = TMTSS*N(16), Transfer occurs at 24-hour intervals from 186 hours into pathway.
TAU169 = (1. - (TMTSS + TMTH + TMTU))*N(16), Transfer occurs at 24-hour intervals from 186 hours.
TA1617 = TMTH*N(16), Transfer occurs at 24-hour intervals from 68 hours for COW = -1.
TA1619 = TMTU*N(16), Transfer occurs at 24-hour intervals from 68 hours for COW = +1.

Compartment 17, UDDER --

This compartment provides for an indirect transfer of MANURE associated pathogens to MILK. Pathogens are transferred from Compartment 16, MANURE, to UDDER by TA1617 once each day. The number transferred is controlled by the variable TMTU. If the dairy cow option is selected (COW = +1.), a fraction of the pathogens on UDDER will be transferred to MILK during each milking. This fraction is specified by the variable UTM.

Time of first transfer into compartment - 68 hours into pathway.

Time of last transfer out of compartment - End of pathway.

Process function - RH017
Activated: 68 hours into pathway.
Duration: Until pathway ends.
Rates: Salmonella: -(TA1617/24.)/hour.
Ascaris: -(TA1617/24.)/hour.
Poliovirus: -(TA1617/24.)/hour.

Transfers into compartment -
TA1617 = TMTU*N(16), Transfer occurs at 24-hour intervals from 68 hours into pathway.
Transfer out of compartment -
TA1715 = UTM*N(17), Transfer occurs at 12-hour intervals from 72 hours.

Compartment 18, GROUNDWATER --

Pathogens applied to a pasture may contaminate groundwaters if surface water percolates deeply enough. The default values incorporated into the model preclude such contamination but, as explained in Compartment 11,

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the user may specify a transfer of pathogens to GROUNDWATER in order to model the effects of heavy irrigation.

Pathogens transferred to GROUNDWATER would slowly be inactivated as shown in the process function listed below. Pathogens would also be dispersed throughout the aquifier. The user may determine the effects of dispersion by specifying a value for GNDIL. This variable is included in the equation for TA1820 and affects the pathogen number transferred to Compartment 20, IRRIGATION WATER. Another variable in the equation for TA1820 is FRGIR. It determines what fraction of the water used for irrigation is from GROUNDWATER by specifying what fraction of the pathogens present will be transferred on. The default values for these variables were not chosen to model any particular situation. One-half of the water in Compartment 20 is from GROUNDWATER while the aquifier dilutes incoming percolation by 1×10^6 when default values are used.

Time of first transfer into compartment - After the first irrigation at 173 hours + (DEPTH/FILTR8) + (80 centimeters/FILTR8).

Time of last transfer out of compartment - 1 hour before last irrigation (577 hours).

Process function - RH018
Activated: At time of first transfer in.
Duration: Until end of pathway.
Rates: Samonella: -0.012*N(18)/hour. (23, 72, 73)
Ascaris: -0.00053*N(18)/hour. (83)
Poliovirus: -0.0119*N(18)/hour. (95)

Transfers into compartment:
TA1118 = SSSTGW*N(11), Transfer occurs after each irrigation at TIRRG + (DEPTH/FILTR8) + (80 centimeters/FILTR8), also after rain at TRAIN + (DEPTH/FILTR8) + (80 centimeters/FILTR8).

Transfers out of compartment -
TA1820 = GNDIL*FRGIR*N(18), Transfer occurs 1 hour before each irrigation.

Compartment 19, HIDE --
This compartment represents the HIDE of the grazing cattle. Each day pathogens are transferred from Compartment 16, MANURE, to HIDE by TA1619. The user may specify the fraction of transfer by supplying a value for TMTH. If the beef cow option is selected (COW = -1.), a fraction of the pathogens on the HIDE will be transferred to MEAT at the time of slaughter on the day specified in TSLOTR. This fraction is specified by variable HTM.

Time of first transfer into compartment - 68 hours into pathway.

Time of last transfer out of compartment - TSLOTR.

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Process function - RH019
Activated: 68 hours in pathway.
Duration: 1 hour.
Rates: Salmonella: -N(19)/hour.
Ascaris: -N(19)/hour.
Poliovirus: -N(19)/hour.

Transfers into compartment -
TA1619 = TMTH*N(16), Transfer occurs at 24-hour intervals from 68 hours.

Transfers out of compartment -
TA1913 = HTM*N(19), Transfer occurs on day TSLOTR, 1 hour after TA1619.

Compartment 20, IRRIGATION WATER --

In this compartment water from two sources is combined. Water is transferred into the compartment from GROUNDWATER by TA1820 and from an EXTERNAL SOURCE by TAU020. GROUNDWATER represents well water used here for irrigation. It may contain pathogens which have been carried through SUBSURFACE SOIL by deep percolation (TA1118). EXTERNAL SOURCE represents surface flows used for irrigation. This water may also contain pathogens. The user may specify the level of contamination by assigning a value to the variable EXTRN. EXTRN may be set to simulate weekly application with liquid sludge by the spread/flow irrigation method. This method is essentially irrigation with a rather highly contaminated EXTERNAL SOURCE water. GNDIL and FRGIR should both be set to zero if weekly sludge irrigation is modeled. The ratio of GROUNDWATER to EXTERNAL SOURCE water is determined by the variable FRGIR.

EXTERNAL SOURCE is not defined as a pathway compartment since it is beyond the scope of this model to consider water pollution other than the possible additive effects of using contaminated water on a sludge-fertilized field. The IRRIGATION WATER compartment has a very short duration and no process functions have been defined. The compartment does not represent a physical part of the environment but rather the transition between several states. As soon as the waters are mixed they become SOIL SURFACE WATER, represented by Compartment 12. This transfer is accomplished by TA2012 at weekly intervals.

Time of first transfer into compartment - 170 hours into pathway.

Time of last transfer out of compartment - Transfers are made from this compartment for each irrigation. The last transfer will occur for the last irrigation at 577 hours.

Process function - RH020
Activated: 170 hours into pathway.
Duration: 1 hour.
Rates: Salmonella: 0.0*N(20)/hour.
Ascaris: 0.0*N(20)/hour.
Poliovirus: 0.0*N(20)/hour.

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Transfers into compartment -

TAU020 = EXTRN, Transfer occurs 1 hour before the first irrigation and then at weekly intervals.

TA1820 = FRGIR*GNDIL*N(20), Transfer occurs 1 hour before the first irrigation and then at weekly intervals.

Transfers out of compartment -

TA2012 = N(20), Transfer occurs at each TIRRG.

Compartment 21, DIRECT CONTACT --

Workers enter the pasture during INCORPORATION and after each irrigation. Sludge adhering to the CROP SURFACE will be transferred by TAU921 to the skin, clothing and shoes of workers and carried out of the pasture. Pathogens transferred to DIRECT CONTACT die off over a 24-hour period.

Time of first transfer into compartment - 29 hours into the pathway.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted following the last transfer into the compartment.

Process function - RHO21

Activated: 29 hours into the pathway.

Duration: 24 hours for each transfer in.

Rates:
- Salmonella: -(TAU921/24.)/hour.
- Ascaris: -(TAU921/24.)/hour.
- Poliovirus: -(TAU921/24.)/hour.

Transfers into compartment -

TAU921 = CSTDC*N(9), Transfer occurs at 29 hours and at 185 hours and then at 7-day intervals.

Transfers out of compartment - None.

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JOB A

PATHWAY 13 - SLUDGE APPLICATION PATHWAY - LIQUID SLUDGE USED AS FERTILIZER FOR CROPS THAT ARE PROCESSED PRIOR TO ANIMAL CONSUMPTION

General Considerations

This pathway describes the fate of sewage sludge pathogens after the application of raw or anaerobically digested liquid sludge to a 1-hectare field planted in a forage crop such as alfalfa. The crop is growing at the time of sludge application and is cut and baled before being used as an animal feed. The pathway can accommodate other processing steps such as ensiling, but these are not included in the model at this time. Figure 13 shows the process compartments and transfers which define this application regime. The differential equations which describe this pathway are presented in Table 13a. Each process and transfer function is defined in the following section. Table 13b lists the definitions of and default values for the input variables used to define environmental factors which affect process and transfer functions. The model user may supply a value for any input variable and, thus, set the program to model a specific situation of concern. Table 13b also lists output variables generated by the computer program. These variables are not available to the user as input but are often used in pathway descriptions to define time increments and pathogen levels. The general considerations and assumptions discussed below were made to facilitate model development.

a. The pathway divides into two parts. The first includes application of sludge to the field, irrigation of the field, growth of the crop, and the cutting and baling of the crop. The second part of the pathway includes storage of the baled crop and consumption of that crop by cows. The duration of the pathway is determined by the user. It is equal to the time when the crop is cut, specified in the variable TCUT; plus a 7-day drying time; plus the time the crop is in storage, specified by the variable STORAG; plus the time the crop is eaten by cows, specified by the variable DAYS. Under default conditions these activities will continue for 99 days. If the beef cow option is chosen (COW = -1.), the pathway will terminate on the day of slaughter specified in the variable TSLOTR, regardless of the values given other time parameters.

   Several cycles of growth and harvest may be simulated by using the final pathogen counts in each compartment as the initial conditions of each compartment in a subsequent run. This is done by specifying each compartment number and the desired pathogen population for each compartment in the POPL variable of the $ARGS name list. The mechanism for setting initial pathogen populations is described in the user's manual for the program (Appendix A).

b. The ambient temperature of the environment is specified for each run of the model by the variable TEMP and remains constant throughout. The default ambient temperature is 20°C.

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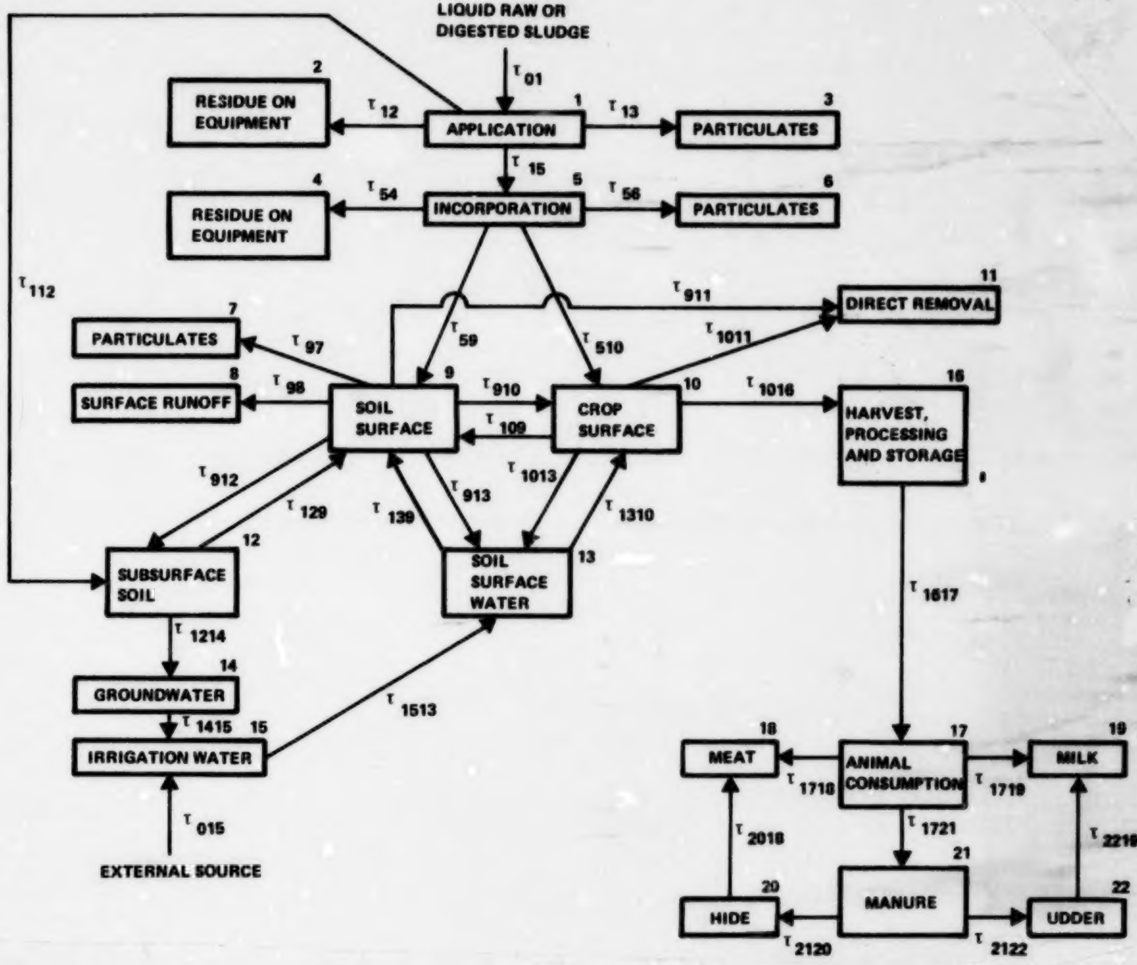
LIQUID RAW OR DIGESTED SLUDGE
τ 01
1 APPLICATION
τ 12
2 RESIDUE ON EQUIPMENT
τ 13
3 PARTICULATES
τ 15
5 INCORPORATION
τ 54
4 RESIDUE ON EQUIPMENT
τ 56
6 PARTICULATES
τ 112
τ 911
11 DIRECT REMOVAL
τ 1011
τ 59
τ 510
7 PARTICULATES
τ 97
8 SURFACE RUNOFF
τ 98
9 SOIL SURFACE
τ 910
τ 109
10 CROP SURFACE
τ 1016
16 HARVEST, PROCESSING AND STORAGE
τ 912
τ 129
τ 139
τ 913
τ 1013
τ 1310
12 SUBSURFACE SOIL
13 SOIL SURFACE WATER
τ 1214
14 GROUNDWATER
τ 1415
15 IRRIGATION WATER
τ 1513
τ 015
EXTERNAL SOURCE
τ 1617
18 MEAT
17 ANIMAL CONSUMPTION
19 MILK
τ 1718
τ 1719
τ 1721
τ 2018
τ 2219
21 MANURE
20 HIDE
22 UDDER
τ 2120
τ 2122

Figure 13. Sludge Application Pathway - Liquid Sludge Used as Fertilizer on Crops that are Processed Prior to Animal Consumption

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TABLE 13a. DIFFERENTIAL EQUATIONS FOR PATHWAY 13

SLUDGE APPLICATION PATHWAY - LIQUID SLUDGE USED AS FERTILIZER ON CROPS THAT ARE PROCESSED PRIOR TO ANIMAL CONSUMPTION

$$\dot{N}_1 = \tau_{01} - \tau_{12} - \tau_{13} - \tau_{15} - \tau_{112} + \rho_1$$

$$\dot{N}_2 = \tau_{12} + \rho_2$$

$$\dot{N}_3 = \tau_{13} + \rho_3$$

$$\dot{N}_4 = \tau_{54} + \rho_4$$

$$\dot{N}_5 = \tau_{15} - \tau_{54} - \tau_{56} - \tau_{59} - \tau_{510} + \rho_5$$

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$$\dot{N}_6 = \tau_{56} + \rho_6$$

$$\dot{N}_7 = \tau_{97} + \rho_7$$

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$$\dot{N}_8 = \tau_{98} + \rho_8$$

$$\dot{N}_9 = \tau_{59} + \tau_{109} + \tau_{129} + \tau_{139} - \tau_{97} - \tau_{98} - \tau_{910} - \tau_{911} - \tau_{912} - \tau_{913} + \rho_9$$

$$\dot{N}_{10} = \tau_{510} + \tau_{910} + \tau_{1310} - \tau_{109} - \tau_{1011} - \tau_{1013} - \tau_{1016} + \rho_{10}$$

$$\dot{N}_{11} = \tau_{911} + \tau_{1011} + \rho_{11}$$

$$\dot{N}_{12} = \tau_{112} + \tau_{912} - \tau_{1214} + \rho_{12}$$

$$\dot{N}_{13} = \tau_{913} + \tau_{1013} + \tau_{1513} - \tau_{139} - \tau_{1310} + \rho_{13}$$

$$\dot{N}_{14} = \tau_{1214} - \tau_{1415} + \rho_{14}$$

$$\dot{N}_{15} = \tau_{1415} + \tau_{015} - \tau_{1513} + \rho_{15}$$

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TABLE 13a (Concluded)

$$\dot{N}_{16} = \tau_{1016} - \tau_{1617} + \rho_{16}$$

$$\dot{N}_{17} = \tau_{1617} - \tau_{1718} - \tau_{1719} - \tau_{1721} + \rho_{17}$$

$$\dot{N}_{18} = \tau_{1718} + \tau_{2018} + \rho_{18}$$

$$\dot{N}_{19} = \tau_{1719} + \tau_{2219} + \rho_{19}$$

$$\dot{N}_{20} = \tau_{2120} - \tau_{2018} + \rho_{20}$$

$$\dot{N}_{21} = \tau_{1721} - \tau_{2120} - \tau_{2122} + \rho_{21}$$

$$\dot{N}_{22} = \tau_{2122} - \tau_{2219} + \rho_{22}$$

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TABLE 13b. VARIABLES FOR PATHWAY 13

SLUDGE APPLICATION PATHWAY - LIQUID SLUDGE USED AS FERTILIZER ON CROPS THAT ARE PROCESSED PRIOR TO ANIMAL CONSUMPTION

POSITION	DEFAULT VALUE	VARIABLES	DEFINITION
		INPUT VARIABLES	
1	1.95E+7 4.95E+2 6.52E+7	ASCRS	Number of pathogens per kilogram of applied sludge.
2	5.607E+7	APRATE	Application rate of sludge in kilograms per hectare.
3	ASCRS*APRATE	ASCIN	Total number of pathogens entering pathway. If present, overrides first two variables
4	20.	TEMP	Ambient temperature throughout pathway in degrees Celsius.
5	+1.	APMETH	Method of applying sludge: +1. = spread/flow 0. = injection -1. = spray.
6	+1.	COW	Animal Type: +1. = milk cow -1. = meat cow.
7	-2.	TRAIN	Time in hours of arbitrary rain. (If -2., there is no rain.)
8	0.1 0.05 0.1	FRAIN	Fraction of total pathogens transferred from Soil Surface to Surface Runoff by rain.
9	8.	DEPTH	Depth of Irrigation Water applied in centimeters.
10	2.	FILTR8	Infiltration rate of Soil Surface Water into the Soil in centimeters per hour.
11	1.0E-6	DILGRN	Groundwater use and dilution.
12	0.5	DILIRR	Fraction of Irrigation Water from Groundwater.

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TABLE 13b. (continued)

POSITION	DEFAULT VALUE	VARIABLES	DEFINITION
13	0.0	COUNT	Number of pathogens introduced into Irrigation Water from External Source (total population).
14	10.	WTRES2	Dry weight of sludge in kilograms left as Residue on equipment used for Application.
15	15.	WPAR3A	Dry weight of particulates in kilograms generated by sludge Application for APMETH = -1.
16	0.0	WPAR3B	Dry weight of particulates in kilograms generated by sludge Application for APMETH = +1. or 0.
17	1.	FSSURA	Fraction of ASCIN transferred to Subsurface Soil during sludge Application when APMETH = 0.0.
18	0.0	FSSURB	Fraction of ASCIN transferred to Subsurface Soil during sludge Application when APMETH = +1. or -1.
19	0.0	WRES4A	Dry weight of sludge in kilograms left as Residue on equipment used during Incorporation when APMETH = 0.0.
20	5.	WRES4B	Dry weight of sludge in kilograms left as residue on equipment used during Incorporation when APMETH = +1. or -1.
21	15.	WTPAR6	Dry weight of particulates in kilograms generated by Incorporation.
22	0.7	TINCSR	Fraction of sludge transferred to Soil Surface during Incorporation.

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TABLE 13b. (continued)

POSITION	DEFAULT VALUE	VARIABLES	DEFINITION
23	5.	WTPAR7	Dry weight of particulates in kilograms generated from Soil Surface.
24	0.00001	SSTCS	Fraction of transfer from Soil Surface to Crop Surface.
25	0.1 0.05 0.1	SSTSSW	Fraction of transfer from Soil Surface to Soil Surface Water.
26	0.001 0.0 0.83	SSTSSS	Fraction of transfer from Soil Surface to Subsurface Soil.
27	0.0125	SSTDR	Dry weight of sludge transferred from Soil Surface to Direct Removal.
28	0.01	CSTSS	Fraction of transfer from Crop Surface to Soil Surface.
29	0.5	CSTSSW	Fraction of transfer from Crop Surface to Soil Surface Water.
30	0.0001	CSTDR	Fraction of transfer from Crop Surface to Direct Removal.
31	0.0	SSSTSS	Fraction of transfer from Subsurface Soil to Soil Surface.
32	-2.	TCULT	Time of cultivation in hours. (If -2., there is no cultivation.)
33	0.1 0.05 0.1	SSWTCS	Fraction to transfer from Soil Surface Water to Crop Surface.
34	0.0	SSSTGW	Fraction of transfer from Subsurface Soil to Groundwater.
35	720.	TCUT	Time of cutting crop in hours.
36	720.	STORAG	Duration of Storage in Compartment 16 in hours.

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TABLE 13b. (continued)

POSITION	DEFAULT VALUE	VARIABLE	DEFINITION
37	30.	ALFALF	Percent of feed which is harvested Crop.
38	7.	WFEED	Weight of feed consumed by each cow.
39	1.	DAYS	Time fed crop.
40	-2.	TSLOTR	Time of slaughter in days. (If -2., there is no slaughter.)
41	0.001	TMTH	Fraction of transfer from Manure to Hide.
42	0.1	HTMT	Fraction of transfer from Hide to Meat at slaughter.
43	0.001	TMTU	Fraction of transfer from Manure to Udder.
44	0.5	UTMK	Fraction of transfer from Udder to Milk.
45	0.0	DTCTMT	Fraction of transfer directly from Animal Consumption to Meat.
46	0.0	DTCTMK	Fraction of transfer directly from Animal Consumption to Milk.
		OUTPUT VARIABLES	
47	(output)	TIRRG	Time elapsed since irrigation.
48	(output)	TCONSP	Time of consumption.
49	(output)	CONSUM	Pathogens consumed per cow per day.

NOTES: The number of pathogens per day entering the pathway will default to APRATE*ASCRS if no value is specified for ASCIN. If a value is specified for ASCIN, it will override the APRATE *ASCRS value.

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TABLE 13b. (concluded)

NOTES: (concluded)

Whenever three default values are specified for any variable in the list above, the order is salmonellae, ascaris, poliovirus pathogen types. The appropriate default value will be selected to agree with the pathogen type being considered in a particular run.

All units of measure are in kilograms, degrees Celsius, or hours unless otherwise stated.

Variables labled "output" are for internal computations and are not available to the user as input.

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c. The amount of sludge applied to the field (APRATE) and the concentration of pathogens in that sludge (ASCRS) are user-specifiable variables. Default values are based on adding 7000 kilograms of sludge per hectare (30 tons per acre) to the field each year (48). One-twelfth of this amount is applied at the start of each pathway run. There are no additional applications of sludge prior to cutting the crop. However, the user may specify a concentration of pathogens in irrigation water. Careful manipulation of this variable can simulate repeated flow-irrigation with liquid sludge. The applied sludge is assumed to be at 5 percent solids. The model accommodates three methods of liquid sludge application: injection 20 centimeters (8 inches) beneath the surface, spray irrigation, and spread/flow irrigation. Spread/flow irrigation (APMETH = +1.) is the method modeled when default values are used.

The default values for the number of pathogens present in the sludge reflect a conservative "worst case" and are set equal to the concentration of each pathogen in raw sludge from a municipal treatment system (1, 4, 28, 32, 77). The value of output variable PTOTL, position 17 of Pathway 10's P-array, is equal to the number of pathogens per kilogram of sludge at the end of a run of Pathway 10. The user may run Pathway 10 for one of the three pathogens and then use the output value of PTOTL as the value for ASCRS, the variable in position 1 of Pathway 13's P-array. ASCRS determines the number of pathogens per kilogram (dry weight) of sludge applied to the field as fertilizer. In this way Pathways 10 and 13 may be linked and a selected pathogen followed through treatment and application of sludge.

d. The field is 1 hectare in size and will produce 1000 kilograms of dry matter per cutting (3).

e. During incorporation, surface-applied sludge is chain harrowed to distribute it evenly over the entire field. A fraction of the applied sludge is knocked to the surface soil while a fraction clings to crop surfaces. The user may specify this distribution using the variable TINCSR. Surface soil is defined as the first 10 centimeters of soil. This zone is affected by changing temperatures and dries after each irrigation. Below the surface soil is the subsurface soil which extends from 10 to 80 centimeters. The depth of this zone was defined to include that soil area from which 90 percent of the water requirements of a forage crop are met (6). The subsurface soil layer is at constant temperature and moisture. Pathogens enter this zone with percolating water or during sludge application by the injection method (APMETH = 0.0). Because injection places sludge 20 centimeters (8 inches) below the soil surface, pathogens are distributed in the subsurface soil during application when this option is active.

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f. Default values for soil factors describe a sandy loam soil. The water infiltration rate (26, 33) and water holding capacity of the soil (80) are functions of soil type and determine the duration of several compartments. Values used in the transfer of pathogens from the surface to subsurface soil zones were based upon the ability of sandy loam soils to filter and adsorb particles of different sizes carrying different charges (4, 89). Variables are provided in the model for soil factors and the fractions of transfer between pathway compartments. The user may specify values for these variables which describe other soil types.

g. The field is irrigated initially by the application of sludge and then once more for each cutting cycle. During spray and spread/flow application of liquid sludge and during irrigation the field is assumed to be flooded to a uniform depth. The irrigation water then infiltrates the soil at a constant and uniform rate. Injected sludge will infiltrate the soil below injection depth as if the soil was uniformly flooded at this depth. The default value for depth of irrigation water (DEPTH) is calculated to allow infiltration of water only 60 to 90 centimeters below the soil surface (6). This will preclude transfers to groundwater, but the user may specify a deeper irrigation which would cause a transfer of pathogens from the subsurface soil to groundwater. The user would have to supply a value for SSSTGW if such a transfer were desired. Infiltrating water will saturate the soil as it percolates downward until the trailing edge transverses the surface soil zone. At this time, the surface soil layer will be at field capacity. The soil in this layer then dries at a rate calculated for sandy loam soils in the Southwest (96). The subsurface soil layer is always at field capacity.

h. The moisture content and temperature of the environment determine the growth and/or inactivation of pathogens.

i. Irrigation water may be pumped from groundwater influenced by irrigation, may be from the diversion of surface flows, or may be a combination of water from both scurces. Variables included in the pathway indicate the dilution factor of pathogens present in groundwater (DILGRN) and the fraction of the total irrigation from this source (DILIRR). The number of pathogens from an external source (COUNT) can be specified. Manipulation of this variable can simulate a second application of liquid sludge by inputting a number of pathogens equal to an application of sludge while zeroing the contribution from groundwater.

j. An optional rain is included in the pathway. If requested, the rain will produce surface runoff which removes a fraction of surface soil associated with pathogens. The values incorporated in the model for intensity and duration of rainfall result in 1/2-inch of rain falling on the field in 24 hours. This produces

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a moderate runoff calculated as one-fourth the peak discharge for a sandy loam soil covered by grass (14).

k. Workers enter the field once during each week of the cutting cycle to check soil moisture and crop growth. They are in direct contact with both the surface soil and crop surface and remove soil and sludge which stick to shoes, clothing, and skin. Default values for direct removal specified in variables SSTDR and CSTRD are estimates of contact. The user may supply values which reflect his own experience.

l. Particulates generated during sludge application and incorporation and at TCUT (the time when the crop is harvested) are assumed to be at a level of 15 milligrams of sludge-fertilized soil per cubic meter of air in a volume extending 10 meters above the area of the field.

m. At the end of a cutting cycle (time set by TCUT) the crop is cut and allowed to field dry for 7 days to a moisture content of 20 percent (6) before being baled. The crop is then stored (time set by STORAG) before being used as a feed.

n. The dried crop is fed to cows which consume 7 kilograms of feed each day (66). The feed is approximately 30 percent crop. The user may vary the percent of sewage-sludge-exposed crop fed to the cattle and the length of time each cow is fed on the prescribed diet by specifying the values of ALFALF and DAYS, respectively. One cutting of the crop will feed 12 cows for 1 month when default values are used.

o. Each cow will eliminate 10 kilograms of manure at 80 percent moisture each day (40, 60). Manure for the entire herd will be deposited at one time each day to simplify process functions. Manure is assumed to dry at a rate which is based on sludge evaporation (10).

p. The user must decide before each pathway run if the cattle being fed the crop are a dairy herd and milked or are a beef herd and slaughtered for meat. If the dairy option (this is the default condition) is selected, cows are milked twice a day at 12-hour intervals. Each cow will deliver 15 liters of milk at each milking (65). The milk is stored at 4°C regardless of the ambient temperature selected for a model run. The total growth of salmonella in milk is limited to 1×10^{12} per liter. If the beef herd option is selected by setting the variable COW to -1., a fraction of the manure which contacts hide will be transferred to meat during slaughter (91). Each cow yields 270 kilograms of meat (53).

q. Salmonella infections in cattle can be systemic (13). Transfers of pathogens directly from the cow to milk and meat are included

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in the pathway (TA1719 and TA1718, respectively). Because infections of adult cattle are usually nonsymptomatic and localized in the mesenteric lymph nodes (5), default values for the fraction of transfer directly to milk and meat (variables DTCTMK and DTCTMT, respectively) are zero for all pathogens. Infections in cattle are assumed to occur whenever the total consumption of salmonella exceeds 1 x 10^9 cells per day. In the event of infection, the number excreted per cow per day in manure is increased to 1 x 10^{12}. Cows cannot be infected by poliovirus or ascaris ova (ascaris in this model always refers to Ascaris lumbricoides). Both are assumed to be unaffected by herbivore digestion and to be excreted in the same numbers as ingested. Milk and meat can be contaminated by contact with manure. All three pathogens can be transferred by this route.

Compartment Descriptions

Compartment 1, APPLICATION --

Liquid sludge is applied to a 1-hectare field by one of three methods. The sludge may be sprayed on (APMETH = -1.), injected 8 inches beneath the surface (APMETH = 0.0), or spread across the field by either a manure spreader or by flow type irrigation (APMETH = +1.). The user must choose one method of application for each run of the model. Each involves a different initial distribution of pathogens between Compartment 3, PARTICULATES; Compartment 9, SOIL SURFACE; and Compartment 10, CROP SURFACE (by way of Compartment 5, INCORPORATION); and Compartment 12, SUBSURFACE SOIL. When liquid sludge is sprayed on, PARTICULATES are generated and the sludge is incorporated into the SOIL SURFACE and contacts the CROP SURFACE. When liquid sludge is injected, PARTICULATES are not generated and the sludge bypasses the SOIL SURFACE and is incorporated directly into the SUBSURFACE SOIL. When liquid sludge is spread or flowed on (spread/flow is considered as a single application method), no PARTICULATES are generated and the sludge is incorporated into the SOIL SURFACE and contacts the CROP SURFACE. Regardless of which application method is chosen, RESIDUE is left on application equipment at the end of compartment activities.

The model controls the initial transfers from APPLICATION to other compartments by the use of paired variables. The weight of sludge transferred by TAU13 to PARTICULATES is determined by WPAR3A when APMETH = -1. and by WPAR3B when APMETH = 1. or 0.0. Similarly, the fraction of input pathogens transferred to SUBSURFACE SOIL (and immediately incorporated) by TAU112 is determined by FSSURA when APMETH = 0.0 but by FSSURB when APMETH = -1. or +1. The pathogens not transferred by TAU112 are transferred to Compartment 5, INCORPORATION, and thence to SOIL SURFACE and CROP SURFACE when the field is harrowed.

This compartment has a 24-hour duration to simulate the time necessary for a field to dry out after surface application of liquid sludge before INCORPORATION (chain-harrowing) can proceed. Process functions provided are those for pathogens in liquid sludge. Injected sludge and its pathogens are not affected by these process functions since TAU112 occurs early in the pathway, transferring these pathogens to SUBSURFACE SOIL.

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Time of first transfer into compartment - Start of pathway.

Time of last transfer out of compartment - 24 hours into pathway.

Process function - RH01
Activated: At the start of the pathway.
Duration: 24 hours.
Rates: Salmonella: 0.13*N(1)/hour, for 20< TEMP < 45 to an upper limit of 1×10^9 salmonella per kilogram (dry weight) of sludge applied. The growth of salmonella in liquid sludge is an estimate based upon one-half the rate of growth for *E. coli* in sterile sludge. (76)
-3.45*N(1)/hour, for TEMP ≥ 45. (8, 93)
0.0*N(1)/hour, for TEMP ≤ 20.
Ascaris: -0.00041*N(1)/hour, for 20 < TEMP < 40. (22, 31, 32, 47)
-1.535*N(1)/hour, for TEMP ≥ 40 (7, 78)
0.00*N(1)/hour, for TEMP ≤ 20.
Poliovirus: -0.01*N(1)/hour, for TEMP < 45. (44, 87)
-0.38*N(1)/hour, for TEMP ≥ 45, (88, 97)

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Transfers into compartment -
TAU01 = ASCIN, Transfer occurs at the beginning of the pathway.

Transfers out of compartment -
TAU12 = (WTRES2/(APRATE - WPAR3_))*N(1), Transfer occurs 8 hours into the pathway.
TAU13 = (WPAR3_/APRATE)*N(1), Transfer occurs 1 hour into the pathway.
TAU15 = N(1), Transfer occurs 24 hours into the pathway.
TAU112 = FSSUR_ *N(1), Transfer occurs 9 hours into the pathway.

Compartment 2, RESIDUE ON EQUIPMENT --

RESIDUE is left on equipment at the end of the APPLICATION compartment. The amount is determined by the variable WTRES2. The default value for this variable is an estimate. The material in RESIDUE compartments is assumed to dry out rapidly. The process functions assigned to this and other RESIDUE compartments reflect the effects of desiccation on the model pathogens.

Time of first transfer into compartment - 8 hours into pathway.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RH02
Activated: 8 hours into pathway.
Duration: Until all pathogens are depleted or the pathway ends.

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Rates:		
	Salmonella:	0.13*N(2)/hour, for % solids of sludge ≤ 70 and $20 \leq TEMP \leq 40$ to an upper limit of $1x10^9$ per kilogram solids. This growth rate is one-half the rate of -0.05*N(2)/hour, for 70 < % solids < 80 and TEMP < 40. (8) -3.45*N(2)/hour, for % solids < 80 and TEMP > 40. (8, 93) -0.46*N(2)/hour, for % solids $\geq$ 80. (8) 0.0*N(2)/hour, for % solids < 80 and TEMP $\leq$ 20.
	Ascaris:	-0.0012*N(2)/hour, for TEMP < 40 and % solids < 95. (40) -1.535*N(2)/hour, for $40 \leq TEMP \leq 50$ and % solids < 95. (7, 78) -0.25*N(2)/hour, for % solids $\geq$ 95. (22, 40, 74)
	Poliovirus:	-0.01*N(2)/hour, for % solids < 65 and TEMP < 45. (44, 87) -0.38*N(2)/hour, for TEMP $\geq$ 45. (88, 97) -0.02*N(2)/hour, for % solids $\geq$ 65 and TEMP < 45. (87)

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Transfers into compartment -

TAU12 = (WTRES2/(APRATE - WPAR3_))*N(1), Transfer occurs 8 hours into pathway.

Transfers out of compartment - None.

Compartment 3, PARTICULATES --

The activities described for Compartment 1 can generate airborne sludge droplets or PARTICULATES. It is assumed in all PARTICULATE compartments that the airborne material is generated at the start of activities in the compartment from which the transfer to PARTICULATES is made, in this case Compartment 1 - APPLICATION, and that the airborne material and its associated pathogens remain at the initial concentration until the generating activity ceases. The process functions in all PARTICULATES compartments are delayed to allow for maximum inhalation of pathogens during generation activities.

The user may specify the amount of sludge being transferred to this compartment by assigning a value to either WPAR3A or WPAR3B. There are three compartments described by the title PARTICULATES in this pathway: Compartment 3, Compartment 6, and Compartment 7. To avoid confusion in this and other pathways, a naming system was used in which the "weight transferred to PARTICULATES" is abbreviated "WTPAR" or "WPAR" and the number of the compartment concerned is appended. The shorter abbreviation is used when more information is needed to describe the variable. In this compartment, the amount of sludge which would become airborne as PARTICULATES depends on the application method. Only spray irrigation should lead

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to particulate generation (APMETH = -1.). Neither spread/flow irrigation nor injection (APMETH = +1. and 0.0, respectively) should result in airborne sludge droplets. Therefore, two variables are provided, WPAR3A for APMETH = -1. and WPAR3B for APMETH = +1. and 0.0. A similar system is used to identify RESIDUE transfer variables. Thus, WTPAR6 is the weight of the sludge transferred to PARTICULATES in Compartment 6 and WPAR3A is the weight of sludge transferred in Compartment 3 when APMETH = -1.

The default value assigned WPAR3A was determined by assuming that PARTICULATES are generated to a level of 15 mg/m³ in a volume extending 10 meters over the 1-hectare field. The concentration of particulates and the height of the volume considered are the same in all PARTICULATES compartments but the area under the cloud differs between pathways.

The process functions for PARTICULATES are the same as for RESIDUE and reflect the effects of rapid dessication of the airborne material and the pathogens associated with it.

Time of first transfer into compartment - 3 hours into pathway.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RHO3
Activated: 8 hours into pathway.
Duration: Until all pathogens are depleted or the pathway ends.
Rates: Salmonella: -0.46*N(3)/hour. (8)
Ascaris: -0.25*N(3)/hour. (22, 40, 74)
Poliovirus: -0.38*N(3)/hour. (88, 97)

Transfers into compartment -
TAU13 = (WPAR3_/APRATE)*N(1), Transfer occurs 2 hours into pathway.

Transfers out of compartment - None.

Compartment 4, RESIDUE ON EQUIPMENT --
RESIDUE is left on equipment at the end of the INCORPORATION compartment. The amount is determined by the variables WRES4A and B. The amount of residue left on equipment following INCORPORATION depends on the method of sludge application chosen. WRES4A is the variable used when the liquid sludge is injected (APMETH = 0.0), while WRES4B is the variable used when sludge is applied on the surface. The default values for these variables are estimates. The material in RESIDUE compartments is assumed to dry out rapidly. The process functions assigned to this and other RESIDUE compartments reflect the effects of desiccation on the model pathogens.

Time of first transfer into compartment - 28 hours into pathway.

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Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RH04
Activated: 28 hours into pathway.
Duration: Until all pathogens are depleted or the pathway ends.
Rates: Salmonella: 0.46*N(4)/hour. (8)
The inactivation of residue-associated salmonella is assumed to occur at the rate for salmonella in drying sludge at greater than 80 percent solids.
Ascaris: -0.25*N(4)/hour. (22, 40, 74)
Poliovirus: -0.38*N(4)/hour. (88, 97)

Transfers into compartment -
TAU54 = (WRES4_/APRATE - WTPAR6)*N(5), Transfer occurs 28 hours into pathway.

Transfers out of compartment - None.

Compartment 5, INCORPORATION --

In compartment 1, sludge is applied to a 1-hectare field planted in a forage crop. The amount is determined by the variable APRATE and the pathogen population by the variable ASCRS. The sludge-covered field is then chain-harrowed, an operation which spreads the sludge evenly over the whole field and knocks some of it from the forage-crop surface to the soil surface. This is INCORPORATION, which distributes the applied sludge between Compartment 9, SOIL SURFACE, and Compartment 10, CROP SURFACE. The user may determine the division of sludge between these two compartments by specifying a value for the variable TINCSR. This variable specifies the percentage of the total pathogen population in applied sludge that reaches the SOIL SURFACE. The remaining sludge is assumed to cling to the forage CROP SURFACE. The default value for TINCSR is an unsupported estimate.

There are four transfers out of this compartment. During harrowing dust is generated. This is simulated by a transfer of sludge-associated pathogens by TAU56 to Compartment 6, PARTICULATES. The amount of sludge transferred, when the default value of WTPAR6 is used, was calculated by assuming the production of 15 milligrams of particulates per cubic meter in a 10-meter high volume above the entire 1-hectare field. This weight of sludge is divided by the weight of sludge applied (APRATE) and is then multiplied by the number of pathogens in Compartment 5 to determine the number of pathogens transferred to PARTICULATES. This transfer occurs 26 hours into the pathway.

Sludge adheres to spreading and harrowing equipment. A weight of sludge specified by the variable WRES4A or B is transferred to Compartment 4, RESIDUE, by TAU54. The amount of residue left on equipment depends on the method of sludge application chosen. WRES4A is the variable used when the sludge is injected (APMETH = 0.0), while WRES4B is the variable used

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when the sludge is applied on the surface. The number of pathogens associated with the transferred sludge is calculated in the same manner as the particulate-associated pathogens above. This transfer occurs 28 hours into the pathway.

At the end of activities for this compartment the transfers are made to Compartment 9, SOIL SURFACE, and to Compartment 10, CROP SURFACE, by TAU59 and TAU510, respectively.

Time of first transfer into compartment - 24 hours into the pathway.

Time of last transfer out of compartment - 28 hours into pathway.

Process function - RHO5
Activated: 24 hours into the pathway.
Duration: 4 hours.
Rates: Salmonella: 0.13*N(5)/hour, for 20 < TEMP < 45 to an upper limit of 1×10^{9} salmonella per gram dry weight of soil. Growth of salmonella in the liquid sludge/soil mixture is an estimate based on one-half the rate of growth for E.coli in sterile sludge. (76)
-3.45*N5)/hour, for TEMP ≥ 45. (8, 96)
0.00*N(5)/hour, for TEMP ≤ 20.
Ascaris: -0.00041*N(5)/hour, for 20 < TEMP < 40 (22, 31, 32, 70)
-1.535*N(5)/hour, for TEMP ≥ 40. (7, 78)
0.0*N(5)/hour, for TEMP < 20.
Poliovirus: -0.01*N(5)/hour, for TEMP < 45. (44, 87)
-0.38*N(5)/hour, for TEMP ≥ 45. (88, 97)

Transfers into compartment -
TAU15 = N(1), Transfer occurs 24 hours into the pathway.

Transfers out of compartment -
TAU54 = (WRES4_/(APRATE-WTPAR6))*N(5), Transfer occurs 28 hours into pathway.
TAU56 = (WTPAR6/APRATE)*N(5), Transfer occurs 26 hours into pathway.
TAU59 = TINCSR*N(5), Transfer occurs at 27 hours into pathway.
TAU510 = (1. - TINCSR)*N(5), Transfer occurs 27 hours into pathway.

Compartment 6, PARTICULATES --
The activities described for Compartment 5 will generate airborne dust or PARTICULATES. It is assumed in all PARTICULATE compartments that the dust is generated at the start of activities in the compartment from which the transfer to PARTICULATES is made, in this case Compartment 5 - INCORPORATION, and that the dust and its associated pathogens remain at the initial concentration until the generating activity ceases. The process functions in all PARTICULATES compartments are delayed to allow for maximum inhalation of pathogens during generation activities.

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The default value assigned WTPAR6 was determined by assuming that PARTICULATES are generated to a level of 15 mg/m^3 in a volume extending 10 meters over the 1-hectare field. The concentration of particulates and the height of the volume considered are the same in all PARTICULATES compartments but the area under the dust cloud differs between pathways.

The process functions for PARTICULATES are the same as for RESIDUE and reflect the effects of rapid desiccation of the airborne material and the pathogens associated with it.

Time of first transfer into compartment - 26 hours into pathway.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RHO6
  Activated: 30 hours into pathway.
  Duration: Until all pathogens are depleted or the pathway ends.
  Rates: Salmonella: -0.46*N(6)/hour. (8)
    Ascaris: -0.25*N(6)/hour. (22, 40, 74)
    Poliovirus: -0.38*N(6)/hour. (88, 97)

Transfers into compartment -
  TAU56 = (WTPAR6/APRATE)*N(5), Transfer occurs 26 hours into pathway.

Transfers out of compartment - None.

Compartment 7, PARTICULATES --
The PARTICULATES generated in this compartment represent the dust raised during cultivation or crop cutting. The dust is blown up from the SOIL SURFACE as simulated by transfer TAU97. The amount of sludge-amended soil involved is specified by assigning a value to WTPAR7. The default value for this variable assumes that 15 milligrams of dust are generated for each cubic meter of air in a 10-meter high volume above the 1-hectare field. The process functions for this compartment are delayed 12 hours to provide for maximum inhalation by workers.

Time of first transfer into compartment - TCULT if this variable is set to a positive number or at TCUT.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RHO7
  Activated: TCULT + 5 hours or TCUT + 5 hours.
  Duration: Until all pathogens are depleted or the pathway ends.
  Rates: Salmonella: -0.46*N(7)/hour. (8)
    Ascaris: -0.25*N(7)/hour. (22, 40, 74)
    Poliovirus: -0.38*N(7)/hour. (88, 97)

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Transfers into compartment -
TAU97 = (WTPAR7/(TINCSR*APRATE))*N(8), Transfer occurs at TCULT and TCUT.

Transfers out of compartment - None.

Compartment 8, SURFACE RUNOFF --

Pathogens are transferred into this compartment from Compartment 9, SOIL SURFACE, only if a rain occurs. The compartment exists to show that the transfer occurs and to keep track of the pathogen population removed. No process functions have been defined for this compartment. It is beyond the scope of this model to follow pathogens washed from a field by storm runoff.

Time of first transfer into compartment - TRAIN.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RHO8
Activated: TRAIN.
Duration: Until all pathogens are depleted or the pathway ends.
Rates: Salmonella: 0.0*N(8)/hour.
Ascaris: 0.0*N(8)/hour.
Poliovirus: 0.0*N(8)/hour.

Transfers into compartment -
TAU98 = FRAIN*(9), Transfer occurs at TRAIN.

Transfers out of compartment - None.

Compartment 9, SOIL SURFACE --

The first 10 centimeters of soil are the SOIL SURFACE. The soil in this compartment is subjected to a moisture cycle which begins with the irrigation of the field. The soil is at field capacity (20 percent weight/weight) after irrigation and dries to the wilting point (4 percent weight/weight). Pathogen process functions are tied to the irrigation cycle. The rate of growth or inactivation of pathogens is dependent on the ambient temperature of the environment and on the available water. The ambient temperature is constant throughout the pathway and is set by the variable TEMP. The available water is a function of the time elapsed since irrigation.

Sludge fertilizer and pathogens are first transferred into this compartment from the INCORPORATION compartment by TAU59. As the pathway progresses there are several other transfers into this compartment. At irrigation, water from Compartment 15, IRRIGATION WATER, is transferred to Compartment 13, SOIL SURFACE WATER. This water then percolates into the

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soil, transferring pathogens to SOIL SURFACE by TAU139. The pathogens involved in this transfer may be either soil pathogens which become suspended in the water during irrigation, a phenomenon simulated by TAU913, or may be transferred to SOIL SURFACE by TAU109 when gravity and wind cause dust and sludge to fall to the ground. If the field is cultivated after planting, pathogens which are in the SUBSURFACE SOIL (Compartment 12) will be transferred to the SOIL SURFACE as the ground is turned. This is simulated by TAU129.

There is one other way for pathogens to enter this compartment. The user may place an initial pathogen population in any pathway compartment by specifying the compartment number and the desired population in the POPL variable of the $ARGS name list. The mechanism for handling variable specification is fully described in the user's manual for the program (Appendix A). Specifying an initial pathogen population allows the user to examine the effects of several sludge applications. The final compartment populations of one model run would be input as initial populations in the next run. Environmental conditions may be unique for each run, or standard default values may be used.

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Pathogens are transferred from this compartment into Compartment 7, PARTICULATES, by TAU97; Compartment 8, SURFACE RUNOFF, by TAU98; Compartment 10, CROP SURFACE, by TAU910; Compartment 12, SUBSURFACE SOIL, by TAU912; Compartment 13, SOIL SURFACE WATER, by TAU913, and to Compartment 11, DIRECT REMOVAL, by TAU911. PARTICULATES are generated by cultivation if TCULT is positive and by crop cutting which occurs at time TCUT. The transfer from SOIL SURFACE to SUBSURFACE SOIL occurs after irrigation as irrigation water percolates below the 10-centimeter mark which separates SOIL SURFACE from SUBSURFACE SOIL. The time of this transfer is controlled by the infiltration rate of SOIL SURFACE WATER, a parameter the user may specify in variable FILTR8. The infiltrating water carries pathogens with it. The fraction of the total population in SOIL SURFACE transferred by percolating water to SUBSURFACE SOIL is specified in the variable SSTSSS. The default values for this variable are estimates that take into account the size and soil-binding capacities of each pathogen.

Pathogens associated with SOIL SURFACE are suspended in irrigation water while it is lying on the surface of the field and is considered to be in Compartment 13, SOIL SURFACE WATER. This transfer occurs at irrigation. The fraction of total SOIL SURFACE pathogens suspended in SOIL SURFACE WATER is determined by the variable SSTSSW. These pathogens and any introduced from IRRIGATION WATER are transferred to SOIL SURFACE by TAU139 when the irrigation water percolates into the soil. Soil and pathogens are transferred to CROP SURFACE constantly as dust is blown up from the SOIL SURFACE. The weight of each transfer is determined by SSTCS. Workers will enter the field weekly to inspect the crop. They will carry dirt away with them on hands, shoes, and clothing. This DIRECT REMOVAL may be quantified in the variable SSTDR.

The transfer to SURFACE RUNOFF simulates the effects of rain and occurs at TRAIN. The rain which produces runoff is an arbitrary event

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which does not occur under default conditions. The user must set TRAIN to a positive number for rain to occur. The number will equal the time in hours when the rain occurs. The user may also control the number of pathogens washed from the SOIL SURFACE and removed from the pathway by TAU911 by specifying the value of FRAIN.

Time of first transfer into compartment - 27 hours into pathway.

Time of last transfer out of compartment - End of pathway.

Process function - RH09
Activated: 27 hours into pathway.
Duration: Until the end of the pathway.
Rates:

Salmonella:
0.070*N(9)/hour, for $20 \leq TEMP < 45$ and $0 < TIRRG \leq 3.5$ days. The growth of salmonella is assumed to occur at one-half the rate for E.coli in sterile compost. (62)
-0.012*N(9)/hour, for $20 < TEMP < 45$ and $3.5 < TIRRG \leq 5.5$ days. (23, 72, 73)
-0.46*N(9)/hour, for $TEMP < 45$ and $5.5 < TIRRG < 7$ days. (8)
-3.45*N(9)/hour, for $TEMP \leq 45$ and any time. (8, 93)
0.0*N(9)/hour, for $TEMP < 20$ and any time. No changes in pathogen population are assumed for temperatures less than 20°C.

Ascaris:
0.0005*N(9)/hour, for $TEMP < 40$ and 8 hours $\leq TIRRG \leq 5.5$ days. (83)
-1.54*N(9)/hour, for $40 \leq TEMP < 50$ and 8 hours $< TIRRG \leq 5.5$ days. (7, 78)
-0.25*N(9)/hour, for $TIRRG < 5.5$ days and any temperature. (22, 40, 74)

Poliovirus:
0.005*N(9)/hour, for $15 < TEMP < 45$ and 8 hours $< TIRRG \leq 6.5$ days. (27, 96)
-0.027*N(9)/hour, for $TEMP < 45$ and $TIRRG > 6.5$ days. (87, 96)
-0.38*N(9)/hour, for $TEMP \geq 45$ and any time. (88, 97)
-0.00087*N(9)/hour, for $TEMP < 15$ and 8 hours $< TIRRG < 6.5$ days. (96)

Transfers into compartment -
TAU59 = TINCSR*N(5), Transfer occurs 27 hours into the pathway.
TAU109 = (CSTSS/24.)*N(10), Transfer occurs at hourly intervals from 27 hours.
TAU129 = SSTSS*N(12), Transfer occurs at TCULT when TCULT > 0.0.
TAU139 = (1. - SSWTCS)*N(13), Transfer occurs at TIRRG + (DEPTH/FILTR8).

Transfers out of compartment -

TAU97 = (WTPAR7/(TINCSR*APRATE))*N(9), Transfer occurs at TCUT and TCULT.
TAU98 = FRAIN*N(9), Transfer occurs at TRAIN.
TAU910 = SSTCS*N(9), Transfer occurs at 24-hour intervals from 50 hours.
TAU911 = (SSTDR/(TINCSR*APRATE))*N(9), Transfer occurs at 7-day intervals from 53 hours and at TCUT.
TAU912 = SSTSSS*N(9), Transfer occurs at TIRRG + (DEPTH/FILTR8) + (10 centimeters/FILTR8).
TAU913 = SSTSSW*N(9), Transfer occurs at TIRRG.

Compartment 10, CROP SURFACE --

In a field with a standing crop, a fraction of the sludge applied would land on the CROP SURFACE; a transfer shown by TAU510. The user can control the distribution of sludge between Compartment 9, SOIL SURFACE, and this compartment by specifying the value of TINCSR. As the pathway progresses there are several other transfers into this compartment. Each day dust is blown up from SOIL SURFACE. Some of it (an amount specified by SSTCS) will cling to the CROP SURFACE. This transfer, TAU910, occurs daily. The crop is washed by irrigation water at TIRRG. As the water soaks into the soil a fraction of the pathogens in Compartment 13, SOIL SURFACE WATER, are transferred by TA1310 to CROP SURFACE. This transfer is determined by the variable SSWTCS.

Pathogens can be transferred from this compartment back to Compartment 9, SOIL SURFACE, as dust and leaves fall to the ground. TAU109 is a continuing transfer throughout the pathway, with a fraction of the total population of Compartment 10, specified by variables CSTSS, transferred each hour. During irrigation, a fraction of the total population (variable CSTSSW is calculated to be that part associated with water-covered foilage when the irrigation depth is 6 inches) is suspended in SOIL SURFACE WATER. This transfer is designated TA1013. Workers in the field contact the CROP SURFACE and remove a fraction of the dust and sludge associated with the crop. This transfer, TA1011, occurs weekly and at TCUT. At TCUT the crop is cut and the pathogen population associated with the crop is transferred to Compartment 16 - HARVEST, PROCESSING, AND STORAGE.

Time of first transfer into compartment - 27 hours into pathway.

Time of last transfer out of compartment - TCUT.

Process function - RHO10
Activated: 27 hours into pathway.
Duration: The duration of the compartment is a variable determined by the value of TCUT.
Rates: Salmonella: 0.096*N(10)/hour. (72, 73)
Ascaris: 1.54*N(10)/hour. (7, 78)
Poliovirus: 0.069*N(10)/hour. (49)

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Transfers into compartment -
TAU510 = (1. - TINCSR)*N(5), Transfer occurs at 27 hours into the pathway.
TAU910 = SSTCS*N(9), Transfer occurs at 24-hour intervals from 50 hours
TA1310 = SSWTCS*N(13), Transfer occurs at TIRRG + (DEPTH/FILTR8).

Transfers out of compartment -
TAU109 = (CSTSS/24.)*N(10), Transfer occurs hourly from 27 hours.
TA1011 = (CSTDR/(1. - TINCSR)*APRATE)*N(10), Transfer occurs at 7-day intervals from 53 hours into the pathway and at TCUT.
TA1013 = CSTSSW*N(10), Transfer occurs at TIRRG.
TA1016 = N(10), Transfer occurs at TCUT.

Compartment 11, DIRECT REMOVAL --

Surface soil, dust, and sludge on the crop, and the pathogens associated with them will adhere to the shoes, clothing, and skin of people who enter the field. These pathogens are directly removed from the field. This transfer occurs weekly. Pathogen populations transferred into this compartment are reduced linearly to zero over a 24-hour period.

Time of first transfer into compartment - 53 hours into pathway.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of this compartment ends when the pathogen population is depleted or when the pathway ends.

Process function - RHO11
Activated: 53 hours into pathway.
Duration: 24 hours for each transfer in.
Rates: Salmonella: -(N(11)/24.)/hour.
Ascaris: -(N(11)/24.)/hour.
Poliovirus: -(N(11)/24.)/hour.

Transfers into compartment -
TAU911 = (SSTDR/(TINCSR*APRATE))*N(9), Transfer occurs at 7-day intervals from 53 hours and at TCUT.
TA1011 = (CSTDR/((1. - TINCSR)*APRATE))*N(10), Transfer occurs at 7-day intervals from 53 hours and at TCUT.

Transfers out of compartment - None.

Compartment 12, SUBSURFACE SOIL --

This compartment represents the soil from 10 to 80 centimeters below the surface. This SUBSURFACE SOIL is at constant moisture (field capacity, 20 percent weight/weight) and temperature (15°C). When the injection method of liquid sludge application is chosen (APMETH = 0.0), the sludge and its associated pathogens are transferred directly into this compartment during APPLICATION by TAU112. A pair of variables, FSSURA and B, determine

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EPA-287 (Cin.)
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the fraction of ASCIN which is transferred directly to SUBSURFACE SOIL. Pathogens from the sludge-fertilized upper 10 centimeters of soil are transferred into this compartment with percolating irrigation water. The fraction of the total SOIL SURFACE (Compartment 9) pathogen population transferred is determined by the variable SSTSSS. The time of the transfer by TAU912 is controlled by the depth of irrigation water which must soak in (DEPTH) and the rate of water infiltration (FILTR8). The transfer occurs after irrigation.

There are two possible transfers out of this compartment. Pathogens may be transferred to Compartment 14, GROUNDWATER, by TA1214. The variable, SSSTGW, which specifies the fraction of total SUBSURFACE SOIL pathogens transferred, is set to zero under default conditions. The 6 centimeters of applied irrigation water specified by default values would only penetrate to 60 centimeters, precluding transfer to GROUNDWATER. The user should specify a value for SSSTGW if DEPTH is set to more than 6 centimeters.

Pathogens may be transferred to Compartment 9, SOIL SURFACE, by TAU129 if the user specifies a positive value for the variable TCULT. This variable indicates that cultivation is to be simulated and sets the time at which the field will be plowed. The variable SSSTSS determines the fraction of SUBSURFACE SOIL pathogens transferred.

Time of first transfer into compartment - 9 hours into the pathway.

Time of last transfer out of compartment - End of the pathway.

Process function - RH012
  Activated: 9 hours.
  Duration: Until all pathogens are depleted or the pathway ends.
  Rates: Salmonella: -0.012*N(12)/hour. (23, 72, 73)
    Ascaris: -0.00053*N(12)/hour. (83)
    Poliovirus: -0.0049*N(12)/hour. (27, 96)

Transfers into compartment -
  TAU112 = FSSUR_*N(1), Transfer occurs 9 hours into the pathway.
  TAU912 = SSTSSS*N(9), Transfer occurs after irrigation at TIRRG + (DEPTH/FILTR8).

Transfers out of compartment -
  TAU129 = SSSTSS*N(12), Transfer occurs at TCULT.
  TA1214 = SSSTGW*N(12), Transfer occurs after irrigation at TIRRG + (DEPTH/FILTR8) + (80 centimeters/FILTR8).

Compartment 13, SOIL SURFACE WATER --

Irrigation in this model involves flooding the field with water or liquid sludge to a uniform depth (specified by the variable DEPTH) and then allowing the water to infiltrate the soil at a constant rate (specified by the variable FILTR8). The water transfers into SOIL SURFACE WATER from

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Compartment 15, IRRIGATION WATER, by TA1513 and may carry with it a pathogen load. Pathogens in SOIL SURFACE and on the CROP SURFACE will become suspended in the overlying water. These transfers from Compartment 9 and Compartment 10, respectively, will occur at irrigation.

Pathogens transfer back to Compartment 9, SOIL SURFACE, and Compartment 10, CROP SURFACE, when the irrigation water soaks into the soil. While this would normally be a gradual process, TAU139 and TA1310 occur at the end of irrigation as a single transfer to each compartment.

Time of first transfer into compartment - 30 hours into pathway.

Time of last transfer out of compartment - TIRRG + (DEPTH/FILTR8).

Process function - RH013
  Activates: 30 hours into pathway.
  Duration: DEPTH/FILTR8.
  Rates: Salmonella: -0.23*N(13)/hour.
    A 3-hour generation time is assumed for growth of salmonella suspended in irrigation water.
  Ascaris: 0.0*N(13)/hour.
  Poliovirus: 0.0*N(13)/hour.
    No change is assumed for ascaris and poliovirus suspended in irrigation water.

Transfers into compartment -
  TAU913 = SSTSSW*N(9), Transfer occurs at TIRRG.
  TA1013 = CSTSSW*N(10), Transfer occurs at TIRRG.
  TA1513 = N(20), Transfer occurs at 366 hours into the pathway.

Transfers out of compartment -
  TAU139 = (1. - SSWTCS)*N(13), Transfer occurs at TIRRG + (DEPTH/FILTR8).
  TA1310 = SSWTCS*N(13), Transfer occurs at TIRRG + (DEPTH/FILTR8).

Compartment 14, GROUNDWATER --

Pathogens applied to a field may contaminate groundwaters if surface water percolates deeply enough. The default values incorporated into the model preclude such contamination but, as explained in Compartment 13, the user may specify a transfer of pathogens to GROUNDWATER in order to model the effects of heavy irrigation.

Pathogens transferred to GROUNDWATER would slowly be inactivated as shown in the process functions listed below. Pathogens would also be dispersed throughout the aquifier. The user may determine the effects of dispersion by specifying a value for DILGRN. This variable is included in the equation for TA1415 and affects the pathogen number transferred to Compartment 15, IRRIGATION WATER. Another variable in the equation for

TA1415 is DILIRR. It determines the fraction of the water used for irrigation that is from GROUNDWATER by specifying the fraction of the pathogens present to be transferred on. The default values for these variables were not chosen to model any particular situation. One-half of the water in Compartment 15 is from GROUNDWATER while the aquifier dilutes incoming percolation by 1×10^6 when default values are used.

Time of first transfer into compartment - After irrigation at TIRRG (DEPTH/FILTR8) + (80 centimeters/FILTR8).

Time of last transfer out of compartment - After last irrigation before TCUT.

Process function - RH014

Activated:	TIRRG + (DEPTH/FILTR8) + (80 centimeters/FILTR8).
Duration:	Until end of pathway.
Rates:	Salmonella: -0.012*N(14)/hour. (23, 72, 73)
	Ascaris: -0.00053*N(14)/hour. (83)
	Poliovirus: -0.0119*N(14)/hour. (95)

Transfers into compartment -

TA1214 = SSSTGW*N(12), Transfer occurs at TIRRG + (DEPTH/FILTR8) + (80 centimeters/FILTR8).

Transfers out of compartment -

TA1415 = DILGRN*DILIRR*N(14), Transfer occurs at TIRRG starting 360 hours into the pathway.

Compartment 15, IRRIGATION WATER --

In this compartment, water from two sources is combined. Water is transferred into the compartment from GROUNDWATER by TA1415 and from an EXTERNAL SOURCE by TAU015. GROUNDWATER represents well water used here for irrigation. It may contain pathogens which have been carried through SUBSURFACE SOIL by deep percolation (TA1214). EXTERNAL SOURCE represents surface flows used for irrigation. This water may also contain pathogens. The user may specify the level of contamination by assigning a value to the variable COUNT. COUNT may be set to simulate repeated applications of liquid sludge by the spread/flow irrigation method. This method is essentially irrigation with rather highly contaminated EXTERNAL SOURCE water. DILIRR and DILGRN should both be set to 0.0 if sludge irrigation is being modeled. The ratio of GROUNDWATER to EXTERNAL SOURCE water is determined by the variable DILIRR.

EXTERNAL SOURCE is not defined as a pathway compartment since it is beyond the scope of this model to consider water pollution other than the possible additive effects of using contaminated water on a sludge-fertilized field. The IRRIGATION WATER compartment has a very short duration, and no process functions have been defined. The compartment does not represent a physical part of the environment but rather the transition between several states. As soon as the waters are mixed they become SOIL SURFACE WATER, represented by Compartment 13. This transfer is accomplished by TA1513.

Time of first transfer into compartment - 360 hours into pathway.

Time of last transfer out of compartment - At last irrigation before TCUT.

Process function - RH015
Activated: 360 hours into pathway.
Duration: 1 hour.
Rates: Salmonella: 0.0*N(15)/hour.
Ascaris: 0.0*N(15)/hour.
Poliovirus: 0.0*N(15)/hour.

Transfers into compartment -
TAU015 = COUNT, Transfer occurs for each TIRRG from 360 hours into the pathway.
TA1415 = DILGRN*DILIRR*N(14), Transfer occurs for each TIRRG from 360 hours into the pathway.

Transfers out of compartment -
TA1513 = N(15), Transfer occurs for each TIRRG from 366 hours into the pathway.

Compartment 16, HARVEST, PROCESSING, AND STORAGE --
The crop is cut at TCUT, the user-specified time to harvest the crop. The crop then sits in the field for 7 days before being baled and stored. At the end of the storage period specified by the variable STORAG, the crop is fed to cows for the number of days specified by the variable DAYS. Process functions defined for this compartment are activated when the crop is cut and continue to affect the pathogens associated with the crop until the last portion is fed to the cows. These process functions simulate the effects of drying and the storage of dry crops on the representative pathogens.

All pathogens associated with CROP SURFACE enter this compartment by TA1016 at TCUT. Pathogens are transferred from this compartment to ANIMAL CONSUMPTION by TA1617 each day from the end of storage until all the crop is consumed. The 1000 kilograms of dry forage cut is assumed to feed 12 cows for 30 days when default values for ALFALF and DAYS are used.

No preparation component is presently included in this compartment. If ensilage or another treatment is to be simulated, the process functions which would describe the treatment should be inserted into the model in this compartment.

Time of first transfer into compartment - TCUT.

Time of last transfer out of compartment - TCUT + 7 days + STORAG + DAYS.

Process function - RH016
Activated: TCUT.
Duration: 7 days + STORAG + DAYS

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Rates: Salmonella: -0.96*N(16)/hour. (72, 73)
Ascaris: -1.54*N(16)/hour. (7, 78)
Poliovirus: -0.069*N(16)/hour. (49)

Transfers into compartment -
TA1016 = N(16), Transfer occurs at TCUT.

Transfers out of compartment -
TA1617 = N(16)/COWS, Transfer occurs at 24-hour intervals from TCUT + STORAG + 7 days.

Compartment 17, ANIMAL CONSUMPTION --

Default values assume that a portion of the stored sludge-fertilized crop is fed to 12 cows once a day for 30 days. This compartment represents the cows as they consume the crop and digest it. Pathogens are transferred into the compartment at 24-hour intervals from Compartment 16 - HARVEST, PROCESSING, AND STORAGE - by TA1617. The transfers begin at TCONSP (TCUT + STORAG + 168 hours). The number of pathogens transferred each day is in proportion to the amount of time the crop is fed (DAYS).

In the absence of data, it was assumed that herbivore digestive processes would not alter ingested pathogen populations. The possibility of infection by salmonella was taken into account. If the total daily transfer of pathogens into the compartment exceeds 1×10^9 salmonella per cow, infection is simulated by increasing the population in the compartment by three orders of magnitude and excreting this larger number in the manure. Transfers TA1719 and TA1718, from ANIMAL CONSUMPTION to MILK and MEAT, may also be used to simulate the effects of salmonella infection. While the default values for both DTCTMT and DTCTMK (the variables which specify the fraction of direct transfer of salmonella from ANIMAL CONSUMPTION to MEAT and MILK, respectively) are zero, the user may input values to indicate contamination of foodstuffs as a result of systemic infection.

Materials which are consumed by the cows have a 2-day residence time before being excreted to MANURE by TA1721. One-half of the pathogen population of Compartment 17 is transferred to Compartment 21 each day as a discrete event.

Time of first transfer into compartment - TCONSP.

Time of last transfer out of compartment - End of pathway.

Process function - RH017
Activated: TCONSP.
Duration: Until the pathway ends.
Rates: Salmonella: If CONSUM $\geq 1 \times 10^9$/cow, there is an immediate increase to 5×10^{12}/cow. If CONSUM $< 1 \times 10^9$/cow, there is no change in the population. 0.0*N(17)/hour.
Ascaris: 0.0*N(17)/hour.
Poliovirus: 0.0*N(17)/hour.

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(4-76)

Transfers into compartment -

TA1617 = N(16)/DAYS, Transfer occurs at 24-hour intervals from (TCUT + STORAG + 7 days).

Transfers out of compartment -

TA1719 = DTCTMK*N(17), Transfer occurs at 12-hour intervals from TCONSP + 38 hours.
TA1718 = DTCTMT*N(17), Transfer occurs at 24-hour intervals from TCONSP + 38 hours.
TA1721 = N(17)/2., Transfer occurs at 24-hour intervals from TCONSP + 40 hours.

Compartment 18, MEAT --

If the beef cow option is chosen (the variable COW is set by the user to -1.), the cows feeding on sludge-fertilized feed will be slaughtered at TSLOTR. Slaughter will occur when pathogen levels in the cows are highest on the day assigned to TSLOTR. At slaughter, the cows become 3240 kilograms of MEAT (12 cows x 270 kilograms per cow). Pathogens can be transferred to MEAT by two routes. Salmonella can infect a cow. TA1718 simulates the direct transfer of pathogens from ANIMAL CONSUMPTION, Compartment 17 to MEAT. The default value for DTCTMT is zero since no data could be found quantifying the contamination of meat from a systemic salmonella infection and neither ascaris nor poliovirus should transfer from the gut of the cow. The user can assign a value to DTCTMT if contamination of MEAT by a systemic infection is desired. This transfer would occur daily but only for salmonella pathogen type.

When cattle are butchered, the MEAT is often contaminated by enteric bacteria. The model shows this transfer as being between the manure-contaminated HIDE and the MEAT. TA2018 will occur at TSLOTR. Default values for HTMT, the fraction of HIDE pathogens transferred to MEAT, are available for all three pathogen types. These are, of course, estimates. MEAT is assumed to be kept at 4°C following slaughter. There are no transfers out of this compartment but the pathogen population is used in meat-exposure risk calculations.

Time of first transfer into compartment - TSLOTR.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathway terminates.

Process function - RH018
Activated: TSLOTR.
Duration: Until the pathway ends.
Rates: Salmonella: 0.076*N(18)/hour to an upper limit of 1 x 10^9 salmonella per kilogram of meat. Salmonella is allowed to grow at a generation time of 6 hours at 4°C.
Ascaris: 0.0*N(18)/hour.

Poliovirus: 0.0*N(18)/hour. Poliovirus and ascaris remain at the level transferred at slaughter.

Transfers into compartment -
TA1718 = DTCTMT*N(17), Transfer occurs at TSLOTR.
TA2018 = HTMT*N(20), Transfer occurs at TSLOTR.

Transfers out of compartment - None.

Compartment 19, MILK --

The cows are milked twice each day when the dairy cow option is chosen (COW = +1.). This is the default condition. The MILK is kept at 4°C for 11 hours but is assumed to be removed from the pathway before the next milking. Pathogens can be transferred to MILK directly from Compartment 17, ANIMAL CONSUMPTION, by TA1719. This transfer will simulate the possible effects of a systemic salmonella infection. The user must supply a value for DTCTMK, the variable which specifies the fraction of Compartment 17 pathogens transferred. The default value for this variable is zero. Neither poliovirus nor ascaris are known to infect cattle and would not pass from the gut.

Pathogens are more readily transferred into milk by dirty utensils and careless handling. In the model these are combined as a transfer from manure-contaminated UDDER, Compartment 22. Transfer TA2219 occurs at each milking. All three pathogens can enter MILK by this route. The default value for UTMK is an estimate. There are no transfers out of this compartment but the pathogen population is used in milk-exposure risk calculations.

Time of first transfer into compartment - TCONSP + 42 hours.

Time of last transfer out of compartment - There are no transfers out of this compartment. Consideration of the compartment ends when the pathway terminates.

Process function - RH019
Activated: TCONSP + 42 hours.
Duration: 11 hours after each milking.
Rates: Salmonella: 0.076*N(19)/hour to a limit of 1 x 10^{12} salmonella per milliliter of milk. Salmonella is allowed to grow at a generation time of 6 hours at 4°C.
Ascaris: 0.0*N(19)/hour.
Poliovirus: 0.0 N(19)/hour.
Poliovirus and ascaris remain at the level transferred in.

Transfers into compartment --
TA1719 = DTCTMK*N(17), Transfer occurs at 24-hour intervals from TCONSP + 42 hours.

+3 lines from C-4

TA2219 = UTMK*N(17), Transfer occurs at 12-hour intervals from
TCSONSP + 42 hours.

Transfers out of compartment - None.

Compartment 20, HIDE --

This compartment represents the HIDE of the cows being fed the sludge-fertilized crop. Each day pathogens are transferred from Compartment 21, MANURE, to HIDE by TA2120. The user may specify the fraction of transfer by supplying a value for TMTH. If the beef cow option is selected (COW = -1.), a fraction of the pathogens on the HIDE will be transferred to MEAT at the time of slaughter on the day specified in TSLOTR. This fraction is specified by the variable HTMT. Pathogens transferred into this compartment are unaffected by process functions for 24 hours, at which time the population is reduced to zero.

Time of first transfer into compartment - TCONSP + 41 hours.

Time of last transfer out of compartment - TSLOTR.

Process function - RH020
Activated: TCONSP + 66 hours and then every 24 hours.
Duration: 1 hour for each 24-hour cycle.
Rates: Salmonella: -N(20)/hour.
Ascaris: -N(20)/hour.
Poliovirus: -N(20)/hour.

Transfers into compartment -
TA2120 = TMTH*N(21), Transfer occurs at 24-hour intervals from
TCONSP + 66 hours.

Transfers out of compartment -
TA2018 = HTMT*N(20), Transfer occurs at TSLOTR.

Compartment 21, MANURE --

Each day one-half of the pathogen population in Compartment 17, ANIMAL CONSUMPTION, is transferred to MANURE by TA1721. The inactivation of pathogens in MANURE is a function of both the ambient temperature of the pathway (set in the variable TEMP) and the moisture content of the manure. Each day's manure dries separately, as shown below in significant calculations.

Depending upon which type of cow is eating the sludge-fertilized crop, a fraction of the deposited MANURE will contact HIDE or UDDER. When the beef cow option is selected (COW = -1.), TA2120 transfers a fraction of the total pathogen population in MANURE (as specified by TMTH) to Compartment 20, HIDE, at the time of deposition. When the dairy cow option is operating (COW = +1.), TA2122 transfers a fraction of the pathogens to Compartment 22, UDDER. These transfers allow indirectly for the contamination of MEAT and MILK.

+2 lines from C-5

Significant calculations - Drying of manure is based upon an 8-centimeter thick layer of 20 percent solids manure evaporating at 0.7 times the clear water evaporation rate for the Albuquerque, New Mexico area.

Percent solids (PRSOL) = 100 - (-5.33T + 80.), where T = days after first deposit of manure.

Time of first transfer into compartment - TCONSP + 40 hours.

Time of last transfer out of compartment - End of pathway.

Process function - RH021
Activated: TCONSP + 40 hours.
Duration: Until the pathway ends.
Rates: Salmonella: -0.46*N(21)/hour, for PRSOL ≥ 80. (8)
-3.45*N(21)/hour, for PRSOL < 80 and TEMP ≥ 45. (8, 93)
-0.048*N(21)/hour, for PRSOL < 80 and TEMP < 45. (8)
Ascaris: -0.251*N(21)/hour, for PRSOL ≥ 95. (22, 40, 74)
-1.535*N(21)/hour, for PRSOL < 95 and TEMP > 40. (7, 78)
0.0*N(21)/hour, for PRSOL < 95 and TEMP < 40.
Poliovirus: -0.384*N(21)/hour, for TEMP ≥ 45. (88, 97)
-0.0192*N(21)/hour, for TEMP < 45 and PRSOL > 65. (87)
-0.0104*N(21)/hour, for TEMP < 45 and PRSOL ≤ 65. (44, 87)

Transfers into compartment -
TA1721 = N(17)/2., Transfer occurs at 24-hour intervals from TCONSP + 40 hours.

Transfers out of compartment -
TA2120 = TMTH*N(21), Transfer occurs at 24-hour intervals from TCONSP + 41 hours.
TA2122 = TMTU*N(21), Transfer occurs at 24-hour intervals from TCONSP + 41 hours.

Compartment 22, UDDER --

This compartment provides for an indirect transfer of MANURE-associated pathogens to MILK. Pathogens are transferred from Compartment 21, MANURE, to UDDER by TA2122 once each day. The number transferred is controlled by the variable TMTU. If the dairy cow option is selected (COW = +1.), a fraction of the pathogens on UDDER will be transferred to MILK during each milking. This fraction is specified by the variable UTMK. Pathogens transferred into this compartment are unaffected by process functions for 24 hours, at which time the population is reduced to zero.

+ 2 lines from C-6

Time of first transfer into compartment - TCONSP + 41 hours.

Time of last transfer out of compartment - End of the pathway.

Process function - RH022
Activated: TCONSP + 66 hours and then every 24 hours.
Duration: 1 hour for each 24-hour cycle.
Rates: Salmonella: N(22) = 0.0.
Ascaris: N(22) = 0.0.
Poliovirus: N(22) = 0.0.

Transfers into compartment -
TA2122 = TMTU*N(21), Transfer occurs at 24-hour intervals from TCONSP + 41 hours.

Transfers out of compartment -
TA2219 = UTMK*N(22), Transfer occurs at 12-hour intervals from TCONSP + 42 hours.

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SECTION 6

RISK ASSESSMENT CAPABILITY OF THE SEWAGE SLUDGE PATHOGEN TRANSPORT MODEL

RISK ASSESSMENT FACTORS

This section describes the risk assessment capability that is incorporated into the Sewage Sludge Pathogen Transport Model and some of the assumptions that were made in the development of this capability.

Risk analysis can be viewed as a composite of five factors which follow one another in a logical progression (71). These five factors include: 1) The causative event; 2) The outcome of the causative event; 3) The exposure of individuals to some hazard resulting from the outcome of the causative event; 4) The consequences of an individual's exposure; 5) The value that is assigned to these consequences.

The use of sewage sludge as a fertilizer, soil amendment, or animal feed supplement constitutes the causative event in an analysis of the human health risks associated with the use of sludge. In the Sewage Sludge Pathogen Transport Model, 13 pathways (Figures 1-13) define the causative events associated with the treatment and application of sewage sludge for beneficial purposes. These pathways are made up of logically interconnected environmental compartments, some of which describe potential sources of human exposure.

For a given causative event there may be a variety of possible outcomes. In this context, the outcome of the causative event is the potential presence of human pathogen populations in the environment. The execution of any of the 13 model pathways leads to an estimate of populations of one of three representative pathogens (salmonella, ascaris, poliovirus) at points in the environment defined by the pathway compartments. These population estimates may be considered as the outcomes of the causative events described by the 13 pathways.

Therefore, the first two elements in an assessment of the pathogen risk associated with the use of sewage sludge are addressed by the structure and execution of the 13 pathways in the Sewage Sludge Pathogen Transport Model.

The completion of the risk assessment process requires consideration of the exposure of individuals to sewage sludge pathogens in the environment, the consequences associated with the exposure, and the value placed upon these consequences. When considering the exposure of individuals to pathogens in the environment, two consequences can result. The individual is either infected as a result of his exposure, or he is not.

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The value an individual places on the positive consequence of being infected is variable and somewhat subjective. Infections may be unapparent; causing no disease. Conversely, the infection may result in a disease with severity that varies from individual to individual. The concern or value that an individual places on illness or the threat of illness may range from total lack of concern to extreme worry over possible death. Because of the highly variable nature of this value factor, it will be assumed that individuals or regulatory agencies place a maximum and constant value on the consequence of being infected with pathogens of sludge origin. This assumption is given support by the promulgation of regulations like those found in 40 CFR Part 257 (Federal Register, Vol. 44, pp. 53438-53468, Sept. 13, 1979) which govern the application of sludge for agricultural purposes.

The consideration of the risk analysis factor of exposure of individuals to pathogens in the environment as a result of sewage sludge use is somewhat complicated. Exposure results only if the individual is knowingly or unknowingly placed within a pathway of exposure to these pathogens. It is possible to estimate the probability of individuals placing themselves in the exposure pathway associated with certain events (e.g., riding in a commercial aircraft). However, because of a lack of documented experience, it is currently impossible to estimate the probability that an individual would find himself in an exposure pathway resulting from the use of sewage sludge. Therefore, for risk analysis purposes, it will be assumed that the individual at risk is within an exposure pathway. This assumption will enable a more critical look at the next logical factor in the risk assessment, the consequences of exposure to pathogens. The Sewage Sludge Pathogen Transport Model contains five exposure risk calculations that are coupled to the various environmental compartments defined in the 13 treatment and application pathways. These calculations provide estimates of the health risks resulting from exposure to sludge pathogens associated with airborne particulates, soil or residue, vegetable crops, meat, and milk. The exposure portion of these calculations defines events that would reasonably be expected to intervene between a human exposure and an environmental compartment in one of the 13 pathways. The calculations associated with these events modify the pathogen populations prior to a potential human exposure. For example, in describing exposure to vegetable crops, the exposure calculations would modify the pathogens present on the crops based on such processes as washing, blanching, freezing, and cooking. The exposed individual would then consume to the final pathogen level as modified by the exposure calculations. Each of these exposure risk calculations and the assumptions made in their development are described in detail in a later portion of this section.

The final risk assessment factor to be considered is the consequence resulting from an exposure to sewage sludge pathogens. As previously stated, one can consider two consequences of exposure to sewage sludge pathogens, infection or no infection. The subject of infection and disease is a complicated one plagued with semantic difficulties. Infection can be defined as the establishment of a pathogen in its host. The infection can be a productive one leading to an increase in pathogen

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numbers within the host as seen with bacteria and viruses. Alternately, the infection may lead to the establishment of an ongoing pathogen-host relationship with no increase in pathogen numbers, as is the case with a parasite like ascaris.

Disease can be defined as a state of detectable abnormality within a host that results from an infection with a pathogenic organism. Whether or not disease results from an infection depends upon a variety of interacting factors. The number of pathogens required to initiate the disease process may be an important contributing factor. Also, the host's previous experience with a pathogen (acquired immunity) and the natural immunity of the host are complex factors that probably determine whether or not infection leads to disease in any given instance.

There is evidence that low numbers of salmonella are capable of initiating infection and disease. However, most volunteer feeding studies indicate that large numbers of salmonella are required to initiate the disease process (41, 42, 54, 55, 56). Because disease is the observable and best-documented consequence of infection with salmonella, disease will be considered as the consequence of exposure to 1 x 10^6 salmonella in the model's exposure risk calculations. Because prior infection with salmonella leads to a short-lived and generally ineffective immune response in the host (64), it will be considered that the exposed individual is totally susceptible.

One viable ascaris ovum is probably capable of initiating infection in a susceptible human host. The single human ingestion study found in the literature indicates that larger doses are usually required (12). One or even several adult ascarids in the intestinal tract are considered a nuisance rather than a disease (50). Only when the numbers of adult ascarids are high is disease, such as intestinal obstruction and interference with the host's nutrient absorption, likely to occur. Additionally, the migration of larvae through liver and lungs after ingested ova hatch may lead to serious immune reactions in the host. If the host is sufficiently sensitized and the number of migrating larvae is large, death may result. Continued exposure to ascaris does confer some immune protection upon the exposed individual, but the nature and extent of the immune response is not well characterized. In the model's exposure risk calculations, infection will be considered as the consequence of exposure of a totally susceptible individual to a single ascaris ovum.

It is generally assumed that one enteric virus is capable of initiating infection and disease in a susceptible host (68, 92). However, this probably does not occur under natural conditions. Depending upon the age and immune status of the host, the most common consequence of infection with enteric viruses is a mild, sometimes subclinical, disease. Once infected, a host generally has lasting immunity against reinfection. Poliovirus was used as a representative enteric virus during model development, but widespread immunization has led to the virtual eradication of the disease in the United States. Hepatitis A and rotavirus infections probably represent the greatest virus hazard to human health from sludge use. To the extent that the inactivation characteristics of poliovirus

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are representative of hepatitis A and rotavirus, the population estimates provided by the model apply to these viruses as well. In the exposure risk calculations, it will be assumed that infection of a totally susceptible individual by a single virus particle is the consequence of exposure to viruses originating in sludge.

To summarize, the pathogen risk associated with the use of sewage sludge is a function of the probability that an individual will be placed in the exposure pathway and the probability that an individual in the exposure pathway will ingest enough pathogens to lead to the consequence of infection and/or disease. This can be stated in the following way:

$$\text{Risk} = F(P_{(e)}, P_{(i/d)}, C)$$

Where: $P_{(e)}$ = The probability that an individual is in the exposure pathway

$P_{(i/d)}$ = The probability of ingestion of sufficient numbers of pathogens

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C = Consequence (infection/disease)

Considering the above definition of risk associated with the use of sewage sludge and the previous general discussion of risk, the risk assessment portion of the model is made up of the following elements:

1. Five exposure risk calculations describe normally expected routes of exposure for man. These calculations are coupled with the appropriate compartments in each of the 13 environmental pathways. The calculations are automatically performed when the model user elects to determine the risk associated with a particular environmental compartment. These exposure risk calculations are discussed in detail in the next portion of this section. Throughout the model, it will be assumed that the individual at risk is placed within the exposure pathway, ($P_{(e)}$ = 1).

2. A separate portion of the exposure risk calculations uses the pathogen population estimates from the selected compartments and data from the literature review relating pathogen numbers to infection or disease to calculate the exposure conditions required for the ingestion or inhalation of an infection/disease-causing dose of pathogens. For example, in the particulate-exposure-risk calculation, the model will determine what volume of air will contain an infection/disease-causing dose of a given pathogen. The model will then calculate the length of time an individual would have to breathe the contaminated air to receive the infection/disease causing dose of pathogens.

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3. Given the model calculation of the amount of crop, air, soil, meat, or milk, that is required to bring about the consequence (C) of infection/disease, the model user will be able to make an inference about the probability of exposure to sufficient pathogens ($P_{(i/d)}$) and consequently, the pathogen risk associated with a sludge treatment and use alternative. For example, a model run using the vegetable exposure-risk calculation may estimate that 100 below-ground crop units (carrots) contain an infectious dose of salmonella. Based upon the model user's experience, it would probably be concluded that the probability of an individual ingesting 100 carrots at a single sitting is low. Consequently, the risk associated with the particular sludge use scenario that yielded a 100-carrot result would also be low.

EXPOSURE RISK CALCULATIONS

Each exposure risk calculation is discussed in detail below. The assumptions that were used in the development of each exposure risk calculation are given. Table 14 lists each compartment of the 13 treatment and application pathways and the single risk calculation which is appropriate for that compartment. Appendix A contains a step-by-step example showing the use of the model and exposure risk calculations. Examples of the output generated by the execution of the model are provided.

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Particulate-Exposure Risk Calculation

Particulates, defined here as airborne dust or droplets, are generated by many of the activities modeled in the sludge treatment and appplication pathways described in Section 5. This material and the pathogens associated with it might be inhaled by people living and working near sludge treatment and application sites. The following section describes the assumptions and calculation used to estimate the possible risk of human infection by salmonella, ascaris, or poliovirus from inhalation of particulate-associated pathogens.

The compartments labeled as PARTICULATES in each pathway represent a cloud containing particles at a user-specified concentration. When default values are used, the concentration is 15 milligrams (dry weight) of sludge-containing material for every cubic meter of space associated with the generating activity. This concentration of particulates was chosen because it is the Occupational Safety and Health Administration's limit for total inert particulates allowed in industrial processes (82). The volume associated with a generating activity is variable. The height of each volume is assumed to be 10 meters, while the length and width differ for each activity and are defined both in the compartment description for the generating activity and in the description for the selected PARTICULATE compartment. For example, in Pathway 1, the area of the drying bed is set at 1255 square meters, so the volume associated with it is 12,550 cubic meters. This volume is used in Compartment 3, the PARTICULATES compartment which represents the dust cloud generated during

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TABLE 14. TYPE OF EXPOSURE RISK CALCULATION WHICH CAN BE MADE FOR EACH PATHWAY COMPARTMENT

Pathway	Compartment	Exposure Risk Calculation Particulate	Residue	Vegetable	Meat	Milk
1	1					
	2	X				
	3		X			
	4		X			
	5	X				
	6					
	7		X			
	8		X			
	9		X			
2	1					
	2	X				
	3		X			
	4		X			
	5	X				
	6					
	7		X			
	8		X			
	9		X			
	10		X			
	11	X				
	12		X			
	13		X			
3	1					
	2		X			
	3					
	4					
	5	X				
	6		X			
	7		X			
	8					
	9	X				
	10		X			
	11		X			
	12	X				
	13		X			
	14		X			
	15		X			
	16		X			
	17	X				
	18		X			
	19		X			
	20	X				

TABLE 14. (continued)

Pathway	Compartment	Exposure Risk Calculation Particulate	Residue	Vegetable	Meat	Milk
3	21					
	22		X			
4	1					
	2		X			
	3	X				
	4	X				
	5		X			
	6		X			
	7					
	8		X			
	9					
	10					
	11					
	12					
	13			X		
5	1					
	2		X			
	3	X				
	4	X				
	5		X			
	6					
	7		X			
	8					
	9				X	
	10					
	11					X
	12		X			
	13					
	14					
	15					
	16					
6	1					
	2		X			
	3	X				
	4	X				
	5		X			
	6		X			
	7					
	8					
	9					
	10		X			

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TABLE 14. (continued)

Pathway	Compartment	Exposure Risk Calculation				
		Particulate	Residue	Vegetable	Meat	Milk
	11					
	12					
	13					X
	14					
	15				X	
	16					
	17		X			
	18					
7	1					
	2		X			
	3					X
	4					
	5				X	
	6					
	7					
	8		X			
	9					
	10		X			
	11	X				
	12		X			
8	1					
	2		X			
	3	X				
	4	X				
	5		X			
	6					
	7		X			
	8					
	9					
	10			X		
9	1					
	2		X			
	3	X				
	4		X			
	5		X			
	6					
	7	X				
	8					
10	1					
	2					
	3		X			

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TABLE 14. (continued)

Pathway	Compartment	Exposure Risk Calculation				
		Particulate	Residue	Vegetable	Meat	Milk
10	4		X			
	5		X			
	6		X			
	7		X			
11	1					
	2		X			
	3	X				
	4		X			
	5					
	6	X				
	7	X				
	8		X			
	9					
	10		X			
	11					
	12		X			
	13					
	14					
	15			X		
	16					
12	1					
	2		X			
	3	X				
	4		X			
	5					
	6	X				
	7	X				
	8		X			
	9					
	10					
	11		X			
	12					
	13				X	
	14					
	15					X
	16		X			
	17					
	18					
	19					
	20					
	21		X			

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TABLE 14. (concluded)

Pathway	Compartment	Exposure Risk Calculation				
		Particulate	Residue	Vegetable	Meat	Milk
13	1					
	2		X			
	3	X				
	4		X			
	5					
	6	X				
	7	X				
	8					
	9		X			
	10					
	11		X			
	12		X			
	13					
	14					
	15					
	16					
	17					
	18				X	
	19					X
	20					
	21		X			
	22					

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removal of sludge from the drying bed. In Pathway 4, the area of the field planted in a vegetable crop is 1 hectare, and the volume of the dust cloud generated by plowing that field during APPLICATION is 100,000 cubic meters.

Particulates are assumed to be evenly distributed throughout the defined volume of an aerosol cloud and the pathogens associated with airborne material are assumed to be uniformly distributed among the particles. In this model the user may specify a weight of sludge-contaminated material transferred to an airborne state. The model then calculates the number of pathogens transferred with that weight of material by determining what fraction of the total weight of sludge-contaminated material is involved. This fraction of the total pathogen population is transferred from the compartment representing the generating activity to the appropriate PARTICULATES compartment. While it is more likely that poliovirus or salmonella will be found in aerosols than the heavier ascaris ova, each model pathogen is treated in the same manner.

The particulate-exposure risk calculation assumes that particulate-associated pathogens are disseminated downwind after generation and that generation is an instantaneous event. The downwind movement leads to a reduction in the concentration of airborne pathogens as a result of diffusion and inactivation. The reduction in pathogen concentration due to diffusion is estimated using Sutton's modification of Pasquill's diffusion equation, which describes release from an instantaneous source (81).

$$\chi(x,y,z;H) = \frac{2Q_T}{(2\Pi)^{3/2}\sigma_x\sigma_y\sigma_z} \exp\left[-\frac{1}{2}\left(\frac{x-ut}{\sigma_x}\right)^2\right] \qquad (1)$$

$$\exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_x}\right)^2\right] \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]$$

where:

$\chi(x,y,z;H)$ = The number of pathogens per cubic meter of air at a downwind location described by the coordinate x,y,z after release from a source at height H
Q_T = The total number of pathogens released
$\sigma_{x,y,z}$ = The standard deviation of the pathogen concentration in a downwind (x), perpendicular (y), and vertical (z) direction
u = Mean wind speed (m/s)
t = Time after release

This expression is simplified in the risk calculations because generation (release) is assumed to occur at ground level (H = 0) and the exposed individual is assumed to be standing directly downwind in the

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center of the particulate cloud ($x = ut$, $y = 0$, $z = 0$). The user may specify the distance (x) in meters between the source and the exposed individual. The dispersion parameters ($\sigma_{x,\ y \text{ and } z}$) set in the model were determined for neutral atmospheric conditions (81). The simplified version of expression 1 appears as part of expression 3 below.

The reduction in pathogens due to inactivation is affected by a number of factors including the age of the cloud, temperature, relative humidity, and solar radiation (16, 24, 35, 52). The following expression was used to estimate inactivation of pathogens dispersed as shown in expression 1 (16, 52).

$$I = e^{\lambda (x/u)} \qquad (2)$$

where: I = The inactivation of the pathogen population
e = Base of natural logarithm
λ = The aerosol inactivation rate constant for a particular pathogen

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The inactivation rate constants used in the model are fiftieth percentile values for the aerosol inactivation rates of salmonella and poliovirus (16) and an estimated value for ascaris. The symbols x and u are as described for expression 1.

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The combined effects of dispersion and inactivation are in expression 3 which predicts the final pathogen concentration.

$$\chi_f = \frac{2Q_T}{2\pi^{3/2}\,\sigma_x\sigma_y\sigma_z} \cdot e^{\lambda (x/u)} \qquad (3)$$

where: χ_f = The final predicted pathogen concentration (pathogens/m^3)
Q_T = The total number of pathogens in a PARTICULATES compartment at a given time N(i) and, therefore, the number released
$\sigma_x = \sigma_y = 0.0295x$, the standard deviation of particulate concentration downward and perpendicular for a specified distance x in meters (81)
$\sigma_z = 0.012x$, the standard deviation of particulate concentration vertically (81).
λ = The inactivation rate constant;
  salmonella - 0.028/second (16)
  ascaris - 0.01/second (16)
  poliovirus - 0.002/second (16)
x = The user-specified distance in meters from the source. The default value for this parameter is zero.
u = The user-specified wind speed (m/s). The default value for the parameter is 4 m/s.

When the default value for x, the distance between the exposed individual and the source, is used, the calculation of χ_f must be

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modified. Since the individual is now standing at the source, the pathogen concentration will equal the number of pathogens in the PARTICULATES compartment (Q_T) divided by the volume of the aerosol cloud.

To calculate the volume of air which must be inhaled by the exposed individual for there to be a risk of infection, other assumptions were made. The exposed individual is assumed to be an adult male respiring 1.2 m^3 of air per hour.* The infectious dose of each pathogen is the same as in the other four exposure risk calculations, 1 x 10^6 salmonella (41, 42, 52, 55, 56, 63), 1 ascaris (50), and 1 poliovirus (68, 92). It is assumed that the pathogens are ingested after inhalation. With the exception of Mycobacterium tuberculosis, agents capable of initiating pulmonary infection are infrequently found in sewage sludge (19). While the site of pathogen infection and multiplication is not always clear, there is no evidence in human studies to indicate that the response to an inhaled dose of the model pathogens differs from an ingested dose (19). It has been suggested that the inhaled dose of salmonella necessary to cause infection is lower (63) but the data are generally from work with animal models.

In order to have the model make a particulate-exposure risk calculation the user must supply appropriate values for the variables in the $RISKN parameter list (the procedure is more fully explained in the user's manual located in Appendix A). Table 15 gives the variable names, default values, and definitions of the user-specifiable variables for all five exposure risk calculations. These variables constitute the $RISKN parameter list. Setting NSTATS equal to a value other than zero flags for risk calculations. Assigning the appropriate compartment numbers to ISTAT() indicates what type of risk calculation and for which compartment. Table 14 provides a list of exposure risk calculations available for each pathway compartment. Compartments labeled PARTICULATES in Figures 1-13 are the only compartments for which particulate-exposure risk calculations will be made.

The user has the option of specifying the distance (in meters downwind) between the particulate source and the exposed individual and the wind speed (m/s) for each pathway run. This is done by changing the values for XDIST and WINDSP in the $RISKN parameter list. All other variables in expression 3 are as shown in the listing below the expression.

The particulate-exposure risk calculation is performed for each hour that the pathogen population in the specified compartment is greater than zero. The print-out for the model run gives the length of time that the exposed individual would have to stay at the given distance from the particulate source to inhale an infectious dose.

Residue-Exposure Risk Calculations

Material left in residue compartments of either sludge treatment or application pathways, sludge- or compost-amended soil, and even sludge-con-

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*Source: ICRP(1975) Report of the Task Group on Reference Man (No. 23).

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TABLE 15. $RISKN PARAMETER LIST

VARIABLE	DEFAULT VALUE	DEFINITION
NSTATS	0.0	Number of compartments for which risk calculations will be made.
ISTAT(i)	0.0	The compartment number (taken from Figures 1-13) of the compartment for which a risk calculation is to be made.

PARTICULATE - EXPOSURE VARIABLES

VARIABLE	DEFAULT VALUE	DEFINITION
XDIST	0.0	Distance (in meters) downwind between particulate source and exposed individual.
WINDSP	4.	Wind speed in meters per second.

VEGETABLE - EXPOSURE VARIABLES

VARIABLE	DEFAULT VALUE	DEFINITION
ICAN	0.0	Flags canning sequence. If ICAN = 1., the vegetable-exposure risk calculation will include the effects of storage of raw vegetable, washing, blanching, canning, storage of cans, and cooking.
IFREE	0.0	Flags freezing sequence. If IFREE = .1, the vegetable-exposure risk calculation will include the effects of storage of raw vegetable, washing, blanching, freezing, frozen storage, and cooking.
ISTRH	1.	Flag for storage of unprocessed vegetables. When ISTRH = 1., the effects of storage on pathogen population are included in the vegetable - exposure risk calculation. When ISTRH = 0.0, these effects are not included.

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TABLE 15 (continued)

VARIABLE	DEFAULT VALUE	DEFINITION
IWASH	1.	Flag for washing.
IBLAN	1.	Flag for blanching.
ICANG	1.	Flag for canning.
ISTRP	1.	Flag for storage of processed vegetables.
ICOOK	1.	Flag for cooking.
IFREG	0.0	Flag for freezing.
TEMP2	7.	Temperature (°C) of unprocessed vegetable storage.
TSTR2	168.	Duration in hours of unprocessed vegetable storage.
TMP7N	20.	Temperature (°C) of canned vegetable storage.
TMP7F	-4.	Temperature (°C) of frozen vegetable storage.
TSTR7	720.	Duration in hours of processed vegetable storage.
COOKS	1.E-30	Multiplication factor controlling the reduction of salmonella during cooking.
COOKA	1.E-5	Multiplication factor controlling the reduction of ascaris during cooking.
COOKP	1.E-5	Multiplication factor controlling the reduction of poliovirus during cooking.

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TABLE 15 (continued)

VARIABLE	DEFAULT VALUE	DEFINITION
	MEAT - EXPOSURE VARIABLES	
TSTM2	720.	Duration in hours of meat storage (unfrozen) between slaughter and freezing.
TMP2M	4.	Temperature (°C) of storage prior to freezing.
TSTR4	120.	Duration in hours of meat storage after freezing.
TEMP4	0.0	Temperature (°C) of storage after freezing.
ICOOK	1.	Flag for cooking.
COOKS	1.E-30	Multiplication factor controlling the reduction of salmonella during cooking.
COOKA	1.E-5	Multiplication factor controlling the reduction of ascaris during cooking.
COOKP	1.E-5	Multiplication factor controlling the reduction of poliovirus during cooking.
	MILK - EXPOSURE VARIABLES	
TMIS2	24.	Duration in hours of raw milk storage.
TEMI2	4.	Temperature (°C) of raw milk storage.
TMIS4	24.	Duration in hours of pasteurized milk storage.
TEMI4	4.	Temperature (°C) of pasteurized milk storage.
PASTA	0.001	Multiplication factor controlling the reduction of ascaris during pasteurization.

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VARIABLE	DEFAULT VALUE	DEFINITION
PASTP	0.001	Multiplication factor controlling the reduction of poliovirus during pasteurization.

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taining animal feed supplement or manure can inadvertently be consumed by people living and working near sludge treatment or use areas. To determine the effects of such consumption, the level of contamination as pathogens per kilogram of material is calculated by dividing the number of pathogens in a selected compartment, N(i), by the weight of material in that compartment. This figure is compared with the infectious dose of the particular pathogen specified for the model run. The number of kilograms of material, at the calculated level of contamination, which must be consumed in order to constitute an infectious dose is then calculated.

The weight of material in each compartment for which a residue-exposure risk calculation can be made (Table 14 lists these compartments) is stored in the program. In some compartments the weight is controlled by a variable. For example, the user can supply the weight transferred to any compartment labeled RESIDUE ON EQUIPMENT by specifying the value of the appropriate WTRES variable. In other compartments the weight is constant. Soil is assumed to have an average density of 2.65 (80). The weight of soil in a SURFACE SOIL compartment in Pathways 4, 5, 6, 11, 12, and 13 is 2.65 x 10^6 kilograms (1 hectare x 10 centimeters deep x 2.65 grams per cubic centimeter). The program calculates the weight of material in MANURE compartments by using the number of cows in the particular pathway, the percent moisture of the drying manure (calculations are found in the appropriate compartment descriptions), and the time since the last removal of manure in pathways where this occurs.

The infectious dose of each pathogen is set; 1 x 10^6 salmonella (41, 42, 52, 56, 63), 1 ascaris ova (50), and 1 poliovirus (68, 92).

To have the model make a residue-exposure risk calculation the user must supply appropriate values for the variables in the $RISKN parameters list (the procedure is explained in the user's manual located in Appendix A). Setting NSTATS equal to a value other than zero flags for risk calculations. Assigning the appropriate compartment numbers to ISTAT( ) indicates that residue-exposure calculations are to be made for the given compartments. Only one type of exposure-risk calculation is appropriate for any particular compartment. The user need not supply any other information to run this calculation because the two factors, level of contamination and infectious dose, are provided in the model. The user indirectly controls level of contamination through variables specifying pathway parameters.

The residue-exposure risk calculation is performed every hour. If the compartment of concern does not contain enough pathogens to constitute an infectious dose, the print-out for the model run indicates this for that 1-hour period. When the compartment does contain enough pathogens, the print-out tells how many kilograms of material would have to be consumed at that point in time to provide an infectious dose.

Vegetable-Exposure Risk Calculation

Pathway 4, Sludge Application Pathway - Fertilizer for Crops Destined for Human Consumption; Pathway 8, Sludge Application Pathway - Residential

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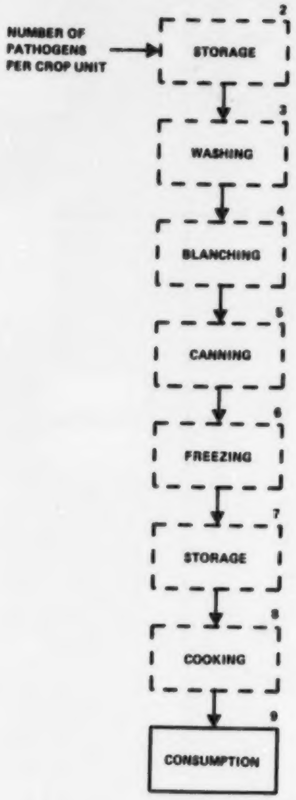
Garden Soil Amendment; and Pathway 11, Sludge Application Pathway - Liquid Sludge Used as a Fertilizer for Crops Destined for Human Consumption - end with the harvest of a vegetable crop. The number of pathogens per crop unit is calculated in the final compartment of each of these pathways and is the figure used by the vegetable-exposure risk calculation. When flagged by specifying the appropriate NSTAT and ISTAT( ) values, the calculation is made once for each pathway run and includes a series of user-selectable processing steps which are diagrammed below. The user has the option of choosing any or all processing steps and of specifying some conditions within processing steps. The variables which control processing are part of the $RISKN parameter list and are detailed in Table 15.



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Harvested vegetables are often stored before being processed. The user selects for storage by setting ISTRH = 1. The user may specify the temperature of storage by assigning a value to TEMP2. The default value of this variable is 7°C. This temperature is within the recommended range for all three of the modeled vegetable types (45, 90). Since the relative humidity of storage is assumed to be between 85 and 90 percent, the storage temperature controls the process functions for this step. Process functions (RHO's) in the vegetable exposure risk calculation are used in a different manner than in the transport model. In this case, the RHO's are part of the expression:

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$$N(2) = N(1) * e^{(RHO * TSTR2)}$$

where:
N(2) = The numbers of pathogens remaining after storage
N(1) = The number of pathogens entering the process series
e = Base of the natural logarithms
TSTR2 = Duration of unprocessed vegetable storage

The RHO values for this step are:

Salmonella:	0.0/hour, for $TEMP2 < 20$. No change is assumed for salmonella during cold storage
	0.7/hour, for $20 < TEMP2 \leq 45$. Growth of salmonella in soil clinging to vegetables is assumed to occur at one-half the rate for E.coli in sterile compost (62).
	-3.45/hour, for $TEMP2 > 45$. (8, 93)
Ascaris:	-0.0005/hour, for $TEMP2 < 40$. (83)
	-1.54/hour, for $TEMP\ 2 > 40$. (7, 78)
Poliovirus:	-0.00087/hour, for $TEMP2 \leq 15$. (96)
	-0.005/hour, for $15 < TEMP2 < 45$. (27, 96)
	-0.38/hour, for $TEMP2 > 45$. (88, 97)

The user may specify a value for TSTR2, the time of unprocessed vegetable storage, which defaults to 1 week. Setting either ISTRH or TSTR2 to zero will eliminate storage from vegetable-exposure risk calculation.

The third step in the process series (step one is the harvest itself) is washing. Vegetables are usually washed before being commercially processed or before being cooked or eaten raw in the home. Both types of washing are designed to remove visible dirt and will also remove 90 percent of the pathogens clinging to fresh vegetables (39). Selecting the washing step by setting IWASH = 1. leads to a 90 percent reduction in pathogens associated with the vegetables being processed.

Blanching follows washing in commercial canning and freezing operations and is designed to clean foods, to shrink them by removing gases, and to inhibit enzymes (39). The process involves temperatures of 82 - 93°C for 3 to 5 minutes. No relevant studies on the effects of commercial blanching operations on the model pathogens were included in the literature review. The effects of this process, as simulated in the risk calculation, were chosen to be a conservative estimate of reductions in pathogen populations due to the high temperatures involved. When IBLAN = 1., the number of salmonella is reduced by five orders of magnitude (45), the number of ascaris by one order of magnitude, and the number of poliovirus by two orders of magnitude.

Commercial canning is a four step process which includes: 1) filling cans; 2) exhausting cans; 3) heat processing; and 4) cooling. Only the effects of heat processing are considered in the canning step of the vegetable-exposure risk calculations. The temperature and duration of

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canning processes vary according to product but are specifically designed to reduce an assumed Clostridium botulinum spore population by 11 orders of magnitude (39, 90). An acidic food, such as tomatoes, might be heated to 120°C for 6 minutes while a low-acid food, such as zucchini or carrots, might be heated to 126.7 - 148.9°C for a similar length of time (39). None of the modeled pathogens are as heat resistant as Clostridium botulinum spores but no data on the reduction of these organisms during canning was found. Therefore, the program reduces each pathogen population by 11 orders of magnitude when canning is included in the processing series.

Setting the variable ICANG = 1. flags for canning. The user may also specify an entire processing sequence which includes canning by setting ICAN = 1. The canning sequence includes the effects of unprocessed vegetable storage, washing, blanching, canning, storage of cans, and cooking on the pathogens associated with harvested vegetables.

A large portion of both home grown and commercial crops are frozen. Step 6 of the vegetable-exposure risk calculation simulates freezing and the subsequent thawing of vegetables. The salmonella population, if present, is reduced by two orders of magnitude (36, 69), while there is no change in the number of ascaris (21) or poliovirus. Freezing is flagged by setting IFREG = 1. or by setting IFREE = 1. IFREE, like the variable ICAN, specifies an entire processing sequence. The freezing sequence includes storage of unprocessed vegetables, washing, blanching, freezing, frozen storage, and cooking. Canned foods are not usually frozen, but the effects of both processes may be included in the processing sequence by setting both ICANG and IFREG to 1. (The default value for IFREG is 0.0. The canning sequence is the default calculation.)

Following canning or freezing most vegetable products are stored for a second time on supermarket shelves and in freezers. The duration and temperature of processed vegetable storage may be specified by the user. The default value of TSTR7 (duration of storage in step 7) is 1 month. Two variables are provided for the temperature parameter. TMPTN has a default value of 20°C and is used when any combination of processing steps not including freezing is specified. TMPTF has a default value of -4°C and is used when freezing is included in a processing sequence (as in step 2 above). Process function values in risk calculations are not used in the same manner as they were in the environmental pathways. Risk calculations may use timed processes but are designed to examine the consequences of a pathogen population at a single point in the environment at a specified time. The RHO values for this step are (TMPT_ = TMPTN or TMPTF):

Salmonella:	-0.000014/hour, for TMPT_ ≤ 0.0 (36)
	0.0/hour, for 0.0 < TMPT_ < 20.
	0.07/hour, for 20 ≤ TMPT_ < 45. (62)
	-3.45/hour, for TMPT_ > 45. (8, 93)
Ascaris:	-0.0005/hour, for TMPT_ ≤ 40. (83)
	-1.54/hour, for TMPT_ > 40. (7, 78)
Poliovirus:	-0.00084/hour, for TMPT_ < 15. (96)
	-0.005/hour, for 15 < TMPT_ < 45. (27, 96)
	-0.38/hour, for TMPT_ > 45. (88, 97)

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Vegetables can be eaten raw or cooked. The vegetable-exposure risk calculation assumes that fresh or processed vegetables are cooked in a small amount of liquid at 100°C for 5 minutes if ICOOK = 1. Little information was found on the effects of cooking on the example pathogens. Therefore, the process functions for this step are variables and may be changed by the user to reflect any available data. It is generally assumed that 15 minutes at 75°C will kill all non-spore-forming bacteria in a food (37). The default values for COOKS, COOKA, and COOKP (the reduction of salmonella, ascaris, and poliovirus, respectively) are 30, five, and five orders of magnitude. The value for salmonella is estimated from a D_{70} value of 1 second (45). The value for ascaris is extrapolated from data at 80°C (22). The value for poliovirus is extrapolated from data at 45°C (87). The user might wish to change the definition of cooking and simulate higher temperatures or include the protective effects of oils or other process-added materials. These changes can be modeled in values assigned to the COOK_ variables.

Regardless of which processing steps are selected, the crop is finally eaten by the individual at risk. All canned vegetables are approximately 90 percent water (90), and a 1/2-cup standard serving weighs 113.5 grams regardless of vegetable type. Frozen vegetables vary slightly in weight and serving size. A survey of available products showed an average of 151.5 grams per serving for carrots or zucchini. Frozen tomatoes are not a standard commercial product. Serving sizes of raw vegetables are one-half a tomato (note that the type of tomato used in our calculations is large, 0.23 kg), one-half a zucchini, and one carrot. The serving sizes of all three vegetables and of all three process stages average 0.10 kilogram of each vegetable. This figure constitutes a serving size in the risk calculation.

After process steps have reduced or increased the initial pathogen load on the vegetables, the number of pathogens remaining is calculated. This number is compared with the infectious dose for each pathogen (salmonella = 1×10^6, ascaris = 1, poliovirus = 1). If not enough pathogens are present over the entire harvested crop to produce an infection, the print-out states this condition. If an infectious dose is present, the program calculates the number of pathogens per serving and prints out the number of servings which must be consumed for an infectious dose to be ingested.

Meat-Exposure Risk Calculation

When the beef cow option is selected in Pathway 5, Sludge Application Pathway - Fertilizer for Pasture Crops; Pathway 6, Sludge Application Pathway - Fertilizer for Crops That Are Processed Prior to Animal Consumption; Pathway 7, Sludge Application Pathway - Animal Feed Supplement; Pathway 12, Sludge Application Pathway - Liquid Sludge Used as Fertilizer for Grazed Pasture; or Pathway 13, Sludge Application Pathway - Liquid Sludge Used as Fertilizer on Crops That Are Processed Prior to Animal Consumption, this exposure risk calculation may be performed on the pathogen population transferred to MEAT at the time of slaughter. The pathway variable TSLOTR determines the day on which slaughter will occur.

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The actual transfers take place when the populations in the HIDE and ANIMAL CONSUMPTION compartments are highest on the day specified in TSLOTR. To accommodate the uncertainty in the hour of transfer, the meat-exposure risk calculation is performed within a 23-hour period from TSLOTR. The calculation is made once. Since the process functions acting on the pathogen population in the MEAT compartment are the same as in the first step of the meat-exposure risk calculation, a delay in the time of the calculation can be accounted for in the duration of raw meat storage.

When a cow is slaughtered, the carcass is washed with a solution of hot water and chlorine, covered with a shroud and cooled to 0°C (30). The effects of this treatment on meat-associated pathogens are not included in either pathway process functions or in the exposure risk calculation. Treatment after slaughter is designed to reduce surface contamination. Since MEAT in the application pathways may be directly contaminated by salmonella and there is no way of distinguishing the source of contamination after transfer to the risk calculation, pathogens associated with meat are treated as if spread evenly throughout the product rather than concentrated on the outside and cut surfaces.

Raw meat is assumed, in the meat exposure risk calculation, to be stored after slaughter. The user may specify the duration and temperature of this processing step by assigning values to TSTM2 and TMP2M. These variables are listed in Table 15. They are part of the $RISKN parameter list. (A complete description of the procedure used to specify risk calculation variables is found in Appendix A.) As in the other risk calculations, the user flags for a meat-exposure risk calculation by setting NSTATS equal to a value other than zero and assigning the appropriate compartment number to ISTAT(). The default value for TSTM2 is 1 month, while the default value for TMP2M is 4°C to model the cold storage common after slaughter (30).

The effects of storage on meat-associated pathogens are the same as on vegetable-associated pathogens. The RHO values for this step are used in the manner described above and are as follows:

Salmonella:	0.0/hour, for TMP2M < 20. No change is assumed for salmonella during cold storage.
	0.7/hour, for 20 < TMP2M ≤ 45. Growth of salmonella is assumed to occur at one-half the rate for E.coli in sterile compost (62).
	-3.34/hour, for TMP2M > 45. (8, 93)
Ascaris:	0.0005/hour, for TMP2M < 40. (83)
	1.54/hour, for TMP2M ≥ 40. (7,78)
Poliovirus:	-0.00087/hour, for TMP2M < 15. (96)
	-0.005/hour, for 15 < TMP2M < 45. (27,96)
	-0.38/hour, for TMP2M ≥ 45. (88,97)

The next step in meat processing is freezing. Commercially processed meat is usually frozen as a way of reducing the possible transfer of parasites to the consumer. Home-processed meats are usually frozen to keep the meat until it is consumed. Furthermore, with the distances between

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processing plant and consumer, most meat is frozen at some time. The effects of freezing on meat-associated pathogens are the same as those given for freezing of vegetables. The salmonella population, if present, is reduced by 12 orders of magnitude (36,69); there is no change in the number of ascaris (21) or poliovirus. The frozen meat is assumed to be stored again. The user may specify the duration of this second storage period by assigning a value to TSTR4; the default value is 5 days. The temperature of storage is also controllable. The default value of TEMP4 models frozen storage at 0.0°C. The user may specify a value to indicate storage at room temperature if the effects of improper storage are to be simulated. The RHO values for this storage step are similar to those given for the first storage period but include a value for the effects of long-term frozen storage on salmonella. The values are:

Salmonella:	0.00014/hour, for $TEMP4 < 0.0$. (36)
	0.0/hour, for $0.0 < TEMP4 < 20$.
	-0.07/hour, for $20 < TEMP4 < 45$. (62)
	-3.45/hour, for $TEMP4 > 45$. (8,93)
Ascaris:	-0.0005/hour, for $TEMP4 < 40$. (83)
	-1.54/hour, for $TEMP4 > 40$. (7,78)
Poliovirus:	-0.00087/hour, for $TEMP < 15$. (96)
	-0.005/hour, for $15 < TEMP4 < 45$. (27,96)
	-0.38/hour, for $TEMP \geq 45$. (88,97)

Thawed meat (the freezing process functions include the effects of thawing on the model pathogens) may be eaten raw or may be cooked. When ICOOK = 1, the meat-exposure risk calculation assumes that meat is cooked at 100°C (as long as food is moist this is the highest temperature reached (90)) for 5 minutes. The short time period reflects the length of time at temperature and disregards the effects of heat while the product is reaching temperature and later cools. Little information was found on the effects of cooking on the example pathogens. Therefore, the process functions for this step in meat processing are variables and may be changed by the user to reflect data available. The default value for COOKS, the reduction in salmonella, is 30 orders of magnitude. The default values for COOKA and COOKP, the reduction in ascaris and poliovirus, respectively, are five orders of magnitude. These values are the same as those used in the vegetable exposure risk calculation cooking step. They are extrapolations from data obtained at lower temperatures (22, 45, 87). Cooking is generally assumed to destroy all vegetative pathogenic forms (37). The values assigned to the cooking variables may be increased to show this or decreased to simulate partial cooking, such as a rare steak. Assigning a value of zero to the appropriate cooking process function variable or assigning a value of zero to ICOOK will simulate consumption of raw meat.

After the process steps described above have reduced or increased the initial pathogen load associated with meat, the number of pathogens remaining is calculated. This number is compared with the infectious dose for the pathogen under consideration (salmonella = 1×10^6, ascaris = 1, poliovirus = 1). If not enough pathogens are present over the entire

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weight of meat to produce an infection, the print-out states this condition. If an infectious dose is present, the program calculates the number of pathogens per 0.117-kilogram (4-ounce) serving, and prints out the number of servings which must be consumed for an infectious dose to be ingested.

Milk-Exposure Risk Calculation

When the dairy cow option is selected in Pathway 5, Sludge Application Pathway - Fertilizer for Pasture Crops; Pathway 6, Sludge Application Pathway - Fertilizer for Crops That Are Processed Prior to Animal Consumption; Pathway 7, Sludge Application Pathway - Animal Feed Supplement; Pathway 12, Sludge Application Pathway - Liquid Sludge Used as Fertilizer for Grazed Pasture; or Pathway 13, Sludge Application Pathway - Liquid Sludge Used as a Fertilizer on Crops That Are Processed Prior to Animal Consumption, this exposure risk calculation may be performed. Each cow delivers 15 liters of milk per milking. The pathogen load transferred to milk is distributed evenly throughout the entire quantity of milk collected from the dairy herd. Herd size varies according to application pathway. Twelve cows constitute the herd in Pathways 5, 6, 12, and 13, while 100 cows are represented in Pathway 7 (when default values are used). The quantity of milk being considered is, therefore, 180 liters per milking in Pathways 5, 6, 12, and 13 and 1500 liters per milking in Pathway 7. Milk from each milking is kept separate. Pathway process functions act upon milk-associated pathogens during the 12 hours between delivery and removal from the pathway. (Milking occurs at 12-hour intervals. The milk from each milking is part of the pathway and assumed to be stored until the next milking when it is removed from consideration to allow for the next delivery.) When the milk-exposure risk calculation is selected by specifying the appropriate values for NSTATS and ISTAT( ), the calculation is performed on the population of the MILK compartment every hour after 32 hours into the pathway under consideration. Raw milk is assumed to be stored, pasteurized, and stored again before being drunk.

The user may specify both the duration and temperature of raw milk storage. Default values are 24 hours for TMIS2 and 4°C for TEMI2 (variables used in this exposure risk calculation are listed in Table 15). The process functions which act upon the pathogen population during this step are the same as those given in the MILK compartments of the application pathways but, as described in the subsection on vegetable-exposure risk calculations, the risk RHO values are used in a different equation since the exposure risk calculations are not integrated. The RHO values for storage are:

Salmonella: 0.0/hour, for $TEMI2 < 4$.
0.076/hour, up to a maximum of 1×10^9 salmonella per liter for $4 \le TEMI2 \le 45$. (62)
-3.45/hour, for $TEMI2 > 45$. (8,93)
Ascaris: 0.0/hour, for $TEMI2 < 40$.
-1.53/hour, for $TEMI2 \ge 40$ (7,78)
Poliovirus: 0.0/hour, for $TEMI2 < 45$.
-0.38/hour, for $TEMI2 \ge 45$ (88,97)

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The user may eliminate the effects of storage from the risk calculation by reducing storage duration to zero.

It is assumed that the milk under consideration for human consumption will be pasteurized. Pasteurization is a rapid heating of a thin layer of milk to 71 - 77°C for 15 seconds. The treatment is designed to reduce the normal bacterial flora of whole milk and eliminate vegetative pathogens. In these calculations, the number of salmonella present will be reduced by nine orders of magnitude (11,45), the number of ascaris by three orders of magnitude (22), and the number of poliovirus by nine orders of magnitude (79) when default values are used. The reduction of ascaris and poliovirus during pasteurization is not well characterized in the literature. Therefore, variables PASTA and PASTP were provided in the model. The user may assign values to these variables which reflect his experience with the effect of pasteurization temperatures on ascaris and poliovirus. Note that the process function is not time dependent but is a single reduction in total population.

After pasteurization, milk would again be stored, usually in a home refrigerator. The user may specify the duration and temperature of this second storage step. The default values for TMIS4 and TEMI4 are the same as for the corresponding variables in the earlier storage step. Process functions during this storage are the same as for raw milk storage and are listed above.

The milk-exposure risk calculation determines the final population of pathogens in the milk after storage and pasteurization. If the total number of pathogens present in the milk is less than the infectious dose for the pathogen being run (1×10^6 salmonella, 1 ascaris, or 1 poliovirus), the program prints out this condition. When the total number of pathogens is equal to or exceeds the infectious dose, the program calculates how many 0.237 liter (1 cup) servings of pasteurized milk must be drunk for an infectious dose to be ingested by the individual at risk and prints out this number.

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Job E

APPENDIX A

MODEL USER'S MANUAL

The model was written in FORTRAN IV to execute on Sandia Laboratories' CDC 6600 under the NOS/BE time-share operating system. When the user has access to this program, the first command is:

```
CALL,PTHGEN (Z=I)
```

Here "I" is the number of the pathway to be run. This executes a procedure file which retrieves the relocatable binary of the model, allows the user to make the necessary changes to the input file, MDLIN2, and loads and runs the program. Figure A-1 lists the procedure file PTHGEN. The model requires subroutines from the FXMATH Library and that core be preset to zeroes. Figure A-2 shows an example of the PTHINP input file.

Figure A-3 shows an example of the MDLIN2 file. Note that the first three lines are Hollerith information, and each can be up to 40 characters in length. This is used as labeling information for the output processor, PTHZRD. The fourth line is the data in the form of 3I2 for MM/DD/YY: month, day, and year. The rest of the input consists of three NAMELIST parameters: ARGS, PRAMS, and RISKN.

ARGS NAMELIST specifies general input to the model. A dollar sign must be in column 2, followed by the NAMELIST name ARGS, followed by zero or more of the parameter list shown in Table A-1. The model will choose the default value of any variable which is not set in the NAMELIST card. Table A-2 lists the pathogen classifications and associated numbers and Table A-3 lists the pathways and associated numbers. To set initial populations for any particular compartment of a pathway, the compartment number must be pulled from the pathway diagrams as shown in Figures 1 through 13.

The PRAMS NAMELIST name enables the user to change up to 66 input variables from their default values to modify the pathway chosen by the variable IPATH in $ARGS. Any variable not changed by specifying that variable's PP number (position number) will retain its default value. The input variables for each pathway and their associated PP numbers are given in Table 1b for Pathway 1, Table 2b for Pathway 2, and so forth for the 13 pathways. The PP number is simply a means to load the input variables into a common array.

To run the Sewage Sludge Pathogen Transport Model with exposure risk calculations, the NAMELIST $RISKN is used. The variables which form this NAMELIST are given in Table 14, which is located in Section 6. The user indicates the number of pathway compartments for which risk calculations

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```
SETTL,1100.
CLEAR.
SET,R1=Z.
IF(R1 .EQ. 1) GOTO,1BM.
IF(R1 .EQ. 2) GOTO,2BM.
IF(R1 .EQ. 3) GOTO,3BM.
IF(R1 .EQ. 4) GOTO,4BM.
IF(R1 .EQ. 5) GOTO,5BM.
IF(R1 .EQ. 6) GOTO,6BM.
IF(R1 .EQ. 7) GOTO,7BM.
IF(R1 .EQ. 8) GOTO,8BM.
IF(R1 .EQ. 9) GOTO,9BM.
IF(R1 .EQ. 10) GOTO10BM.
IF(R1 .EQ. 11) GOTO11BM.
IF(R1 .EQ. 12) GOTO12BM.
IF(R1 .EQ. 13) GOTO13BM.
GOTO,EXIT.
1BM,GET,MODELT=MODE1B.
GOTO,14BM.
2BM,GET,MODELT=MODE2B.
GOTO,14BM.
3BM,GET,MODELT=MODE3B.
GOTO,14BM.
4BM,GET,MODELT=MODE4B.
GOTO,14BM.
5BM,GET,MODELT=MODE5B.
GOTO,14BM.
6BM,GET,MODELT=MODE6B.
GOTO,14BM.
7BM,GET,MODELT=MODE7B.
GOTO,14BM.
8BM,GET,MODELT=MODE8B.
GOTO,14BM.
9BM,GET,MODELT=MODE9B.
GOTO,14BM.
10BM,GET,MODELT=MOD10B.
GOTO,14BM.
11BM,GET,MODELT=MOD11B.
GOTO,14BM.
12BM,GET,MODELT=MOD12B.
GOTO,14BM.
13BM,GET,MODELT=MOD13B.
14BM,GET,ODEBO.
REWIND,MODELT.
REWIND,ODEBO.
COPYBF,MODELT,MODELX.
COPYBF,ODEBO,MODELX.
PACK,MODELX.
REWIND,MODELX.
RETURN,MODELT,ODEBO.
GET,MDLIN2.
POST,OUTPUT,4. MAKE ANY LAST MINUTE PERMANENT CHANGES TO MDLIN2.
XEDIT,MDLIN2.
REPLACE,MDLIN2.
LDSET,PRESET=ZERO.
LDSET,MAP=SBEX/MDLMAP.
MODELX.
EXIT.
END OF FILE
-
```

A-1

Figure A-1. Pathogen procedure file - for executing model.

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```
  $FILES NFILE=1$
  $ICTRL IDUMP=-1,ISTATE=1,ISTAT(1)=13,IPLOT=0,ISUPRS=0$
  $PLOT ISIZE=6,IPAGE=0,IBOX=11,ILABEL=1,IMARK=100,IAXES=1,ITYPE=1,
     RANGE(1)=1.0,RANGE(2)=0.0, RANGE(4)=0.0$
 ASCARIS FEED TREATMENT
 POPULATION
 TIME
  EOI ENCOUNTERED.
```

Figure A-2. Example PTHINP input file.

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```
>? P*
SEWAGE SLUDGE PATHOGEN TRANSPORT MODEL
CURRENT VERSION - 15 MARCH 1980
MODIFICATIONS AND ENHANCEMENTS
 31580
 $ARGS TDONE=1200.,IPATH=1,ITYPE=1,IOUT=2$
 $PRAMS PP(1)=1.0E8,PP(4)=-1.,PP(10)=1000.$
 $RISKN NSTATS=1,ISTAT(1)=2,XDIST=5.$
 ISTRP=0,ICOOK=0$
END OF FILE
>? B
```

Figure A-3. Example MDLIN2 input file.

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Job 6

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TABLE A-1. $ARGS PARAMETER LIST

VARIABLE	DEFAULT	DEFINITION
TSTART	0.	Start time of pathway in hours
RERR	1.0E-07	Relative error between integration steps
AERR	1.0E-04	Absolute error of integration step
TDONE	2400.	End time of pathway in hours
IPATH	1	Pathway number
ITYPE	2	Pathogen type (ASCARIS)
POPL (I)	0.	Initial populations of states I = 1 to maximum number of states in pathway
IOUT	1	Output select flag 1 → Terminal only (Device 6) 2 → Tape 3 only 3 → PTHOUT only (via Buffer Out) 4 → Tape 3 and PTHOUT 11 → Terminal only (Device 6) 12 → Tape 3 only

NOTE: Values for IOUT < 10 will produce time and populations only for output. Values for IOUT > 10 will produce time, populations of each state, the transfer function values (TAUS), the process function values (RHOS), and the parameter list (P array) as output. Results of exposure risk calculations will be printed in all cases except when the file PTHOUT is used.

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TABLE A-2. PATHOGEN CLASSIFICATIONS (ITYPE)

PATHOGEN	CLASSIFICATION NUMBER
SALMONELLA	1
ASCARIS	2
POLIOVIRUS	3

TABLE A-3. PATHWAY CLASSIFICATIONS (IPATH)

PATHWAY	CLASSIFICATION NUMBER
General Sludge Treatment	1
Animal Feed Supplement (Treatment)	2
Composting of Raw or Digested Sludge	3
Fertilizer for Crops Destined for Human Consumption	4
Fertilizer for Pasture Crops	5
Fertilizer for Crops That Are Processed Prior to Animal Consumption	6
Animal Feed Supplement (Application)	7
Residential Garden Soil Amendment	8
Residential Lawn Soil Amendment	9
Liquid Sludge (Treatment)	10
Liquid Sludge Used as a Fertilizer for Crops Destined for Human Consumption	11
Liquid Sludge Used as Fertilizer for Grazed Pasture	12
Liquid Sludge Used as Fertilizer on Crops That Are Processed Prior to Animal Consumption	13

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are to be made by specifying a value for the NSTATS parameter. The default value of NSTATS is 0.0. No exposure risk calculations are made under default conditions. Specifying NSTATS = 25. will give risk calculations for all pathway compartments for which human exposure is probable. Table 15 (in Section 6) lists the type of exposure risk calculation which will be made for each compartment in the model. Only one type of calculation is appropriate for each compartment and several compartments do not involve probable human exposure. Any number of compartments can be specified by NSTATS. The particular ones are identified in the ISTAT( ) parameter of $RISKN. The user assigns the number of the pathway compartments (as given in Figures 1-13 and used to identify compartments in the descriptions in Section 5) for which risk calculations are to be made to the ISTAT( ) array which is indexed from 1 to the number assigned NSTATS. For example, if exposure risk calculations were to be made for Compartments 2 and 10 in Pathway 8, the NAMELIST $RISKN would contain NSTATS = 2, ISTAT(1) = 2, ISTAT(2) = 10. Compartment 2 is RESIDUE LEFT ON EQUIPMENT, so the residue-exposure risk calculation would be performed on the pathogen population in this compartment. Compartment 10 of Pathway 8 is HARVESTING AND PREPARATION so the vegetable-exposure risk calculation would be performed on the pathogen population associated with harvested vegetables in this compartment. The calculations made can be modified by the other parameters in the $RISKN parameter list.

When enough pathogens are present in a compartment to constitute an infectious dose, the results of the exposure risk calculation will be included in the output. Otherwise, either the output will state that not enough pathogens are present or no calculation will be made.

OUTPUT

The user may specify six different modes of output from the model by varying the IOUT parameter in NAMELIST ARGS (Table A-4). If this parameter is not specified, the default value 1 sends output to the user's terminal only. Figure A-4 lists an example of the on-line terminal output for IOUT = 1.

The pathogen name is listed first, followed by the initial pathogen population input to the pathway. This line is followed by the maximum duration of the pathway called the integration period. Then, each time (hour) is printed out followed by State 1, State 2, State 3, etc., up to the last state (compartment) with a pathogen population at that given time in the pathway. The results of any risk calculations will be printed under the time and population listing. If the variable IOUT was set equal to 2 or 4, then on-line terminal output would not occur and a file called TAPE3 would be created instead. This local file can be dispatched to the central site high-speed line printer by the following NOS commands:

```
REWIND,TAPE3.
PRINT,TAPE3.
```

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TABLE A-4. OUTPUT MODES (IOUT)

IOUT VALUE	OUTPUT MODE	PARAMETERS
1	User terminal only	time, populations
2	local file - can be dumped to high-speed printer	time, populations
3	PTHOUT (input file to output processor)	time, populations
4	Local file - can be dumped to high-speed printer	time, populations
11	User terminal only	time, populations, TAU, RHO, P array
12	Local file - can be dumped to high-speed line printer	time, populations, TAU, RHO, P array

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 TIME                  POPULATIONS OF COMPARTMENTS 1 THROUGH  9
-------   ------------------------------------------------------------
     1.0  8.306E+09  1.000E+06  0.         0.         0.         0.
          0.         0.         0.
 COMPARTMENT  2 BREATHING  .126E+08 MIN AT    0.0 M FOR INFECTIOUS DOSE
     2.0  1.656E+10  1.000E+06  0.         0.         0.         0.
          0.         0.         0.
 COMPARTMENT  2 BREATHING  .126E+08 MIN AT    0.0 M FOR INFECTIOUS DOSE
     3.0  2.475E+10  1.000E+06  0.         0.         0.         0.
          0.         0.         0.
 COMPARTMENT  2 BREATHING  .126E+08 MIN AT    0.0 M FOR INFECTIOUS DOSE
     4.0  3.290E+10  1.000E+06  0.         0.         0.         0.
          0.         0.         0.
 COMPARTMENT  2 BREATHING  .126E+08 MIN AT    0.0 M FOR INFECTIOUS DOSE
     5.0  4.099E+10  1.000E+06  0.         0.         0.         0.
          0.         0.         0.
 COMPARTMENT  2 BREATHING  .126E+08 MIN AT    0.0 M FOR INFECTIOUS DOSE
     6.0  4.902E+10  1.000E+06  0.         0.         0.         0.
          0.         0.         0.
 COMPARTMENT  2 BREATHING  .126E+08 MIN AT    0.0 M FOR INFECTIOUS DOSE
     7.0  5.701E+10  1.000E+06  0.         0.         0.         0.
          0.         0.         0.
 COMPARTMENT  2 BREATHING  .126E+08 MIN AT    0.0 M FOR INFECTIOUS DOSE
     8.0  6.494E+10  1.000E+06  0.         0.         0.         0.
          0.         0.         0.
 COMPARTMENT  2 BREATHING  .126E+08 MIN AT    0.0 M FOR INFECTIOUS DOSE
     9.0  7.281E+10  1.000E+06  0.         0.         0.         0.
          0.         0.         0.
 COMPARTMETN  2 BREATHING  .126E+08 MIN AT    0.0 M FOR INFECTIOUS DOSE
    10.0  8.064E+10  1.000E+06  0.         0.         0.         0.
          0.         0.         0.
```

Figure A-4. On-line terminal output example.

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Figure A-5 lists an example of TAPE3. This file was intended for lengthy output and hard copy capability for terminals with a CRT screen. The pathway number and pathogen type are given followed by the hour and populations in each compartment of the pathway. As many compartments as possible are included on each line (along with the time) before continuing to the next line. The results of any risk calculations are printed under the time and population listing.

Next, if IOUT is set to 3 or 4, then the input file (PTHOUT) to the output processor (PTHZRD) is created instead of terminal output. This is illustrated in Figure A-6. This file is produced by FORTRAN BUFFER OUT statements and cannot be examined directly without the use of the PTHZRD program.

Finally, IOUT set to 11 or 12, corresponding respectively to IOUT = 1 or 2, presents five parameters: time, population, TAUs, RHOs, and P array with risk calculations, when applicable, printed below the times and populations.

OUTPUT PROCESSOR

The PTHZRD program serves as an output processor to the model utilizing the file PTHOUT created by the model. This program can be used to dump the file PTHOUT and/or can be used to produce line-printer plots of populations versus time for any state of the pathway. The procedure file PR (as listed in Figure A-7) executes the PTHZRD program.

The file, PTHINP, is the user-supplied input file that tells the PTHZRD program what to do with the PTHOUT file created by the model. Figure A-2 lists an example of the PTHINP input file. This file is in card image format and its structure is defined in Table A-5. The actual plot subroutines are the line printer plot routines from the Applied Mathematics Division of Sandia Laboratories. Figure A-6 lists the structure of the PTHOUT file. Table A-6 defines its contents. Figure A-8 illustrates the overall flow diagram. PTHOUT must be a local file when the procedure file PR is called.

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(6-76)

```
PATHWAY NUMBER 1   PATHOGEN TYPE 1
   1.0   9.683E+15  0.           5.635E+15  0.       0.       0.       0.       0.       0.
   2.0   3.562E+15  0.           1.176E+16  0.       0.       0.       0.       0.       0.
   3.0   1.310E+15  0.           1.276E+16  0.       0.       0.       0.       0.       0.
   4.0   4.821E+14  0.           1.233E+16  0.       0.       0.       0.       0.       0.
   5.0   1.773E+14  0.           1.116E+16  0.       0.       0.       0.       0.       0.
   6.0   6.524E+13  0.           1.009E+16  0.       0.       0.       0.       0.       0.
   7.0   2.400E+13  0.           9.134E+15  0.       0.       0.       0.       0.       0.
   8.0   8.830E+12  0.           8.265E+15  0.       0.       0.       0.       0.       0.
   9.0   3.248E+12  0.           7.478E+15  0.       0.       0.       0.       0.       0.
  10.0   1.195E+12  0.           6.767E+15  0.       0.       0.       0.       0.       0.
  11.0   4.396E+11  0.           6.123E+15  0.       0.       0.       0.       0.       0.
  12.0   1.617E+11  0.           5.540E+15  0.       0.       0.       0.       0.       0.
  13.0   5.949E+10  0.           5.013E+15  0.       0.       0.       0.       0.       0.
  14.0   2.189E+10  0.           4.536E+15  0.       0.       0.       0.       0.       0.
  15.0   8.052E+09  0.           4.104E+15  0.       0.       0.       0.       0.       0.
  16.0   2.962E+09  0.           3.714E+15  0.       0.       0.       0.       0.       0.
  17.0   1.090E+09  0.           3.360E+15  0.       0.       0.       0.       0.       0.
  18.0   4.009E+08  0.           3.040E+15  0.       0.       0.       0.       0.       0.
  19.0   1.475E+08  0.           2.751E+15  0.       0.       0.       0.       0.       0.
  20.0   5.425E+07  0.           2.489E+15  0.       0.       0.       0.       0.       0.
  21.0   1.996E+07  0.           2.252E+15  0.       0.       0.       0.       0.       0.
  22.0   7.342E+06  0.           2.038E+15  0.       0.       0.       0.       0.       0.
  23.0   2.701E+06  0.           1.844E+15  0.       0.       0.       0.       0.       0.
  24.0   9.936E+05  0.           1.669E+15  0.       0.       0.       0.       0.       0.
  25.0   3.655E+05  0.           1.510E+15  0.       0.       0.       0.       0.       0.
  26.0   1.345E+05  0.           1.366E+15  0.       0.       0.       0.       0.       0.
  27.0   4.947E+04  0.           1.236E+15  0.       0.       0.       0.       0.       0.
  28.0   1.820E+04  0.           1.119E+15  0.       0.       0.       0.       0.       0.
  29.0   6.695E+03  0.           1.012E+15  0.       0.       0.       0.       0.       0.
  30.0   2.463E+03  0.           9.158E+14  0.       0.       0.       0.       0.       0.
  31.0   9.061E+02  0.           8.286E+14  0.       0.       0.       0.       0.       0.
  32.0   3.333E+02  0.           7.498E+14  0.       0.       0.       0.       0.       0.
  33.0   1.226E+02  0.           6.784E+14  0.       0.       0.       0.       0.       0.
  34.0   4.511E+01  0.           6.139E+14  0.       0.       0.       0.       0.       0.
  35.0   1.660E+01  0.           5.554E+14  0.       0.       0.       0.       0.       0.
  36.0   6.105E+00  0.           5.026E+14  0.       0.       0.       0.       0.       0.
  37.0   2.246E+00  0.           4.548E+14  0.       0.       0.       0.       0.       0.
  38.0   0.         0.           4.115E+14  0.       0.       0.       0.       0.       0.
  39.0   0.         0.           3.723E+14  0.       0.       0.       0.       0.       0.
  40.0   0.         0.           3.369E+14  0.       0.       0.       0.       0.       0.
  41.0   0.         0.           3.048E+14  0.       0.       0.       0.       0.       0.
  42.0   0.         0.           2.758E+14  0.       0.       0.       0.       0.       0.
  43.0   0.         0.           2.496E+14  0.       0.       0.       0.       0.       0.
  44.0   0.         0.           2.258E+14  0.       0.       0.       0.       0.       0.
  45.0   0.         0.           2.043E+14  0.       0.       0.       0.       0.       0.
  46.0   0.         0.           1.849E+14  0.       0.       0.       0.       0.       0.
  47.0   0.         0.           1.673E+14  0.       0.       0.       0.       0.       0.
```

Figure A-5. TAPE3 output example.

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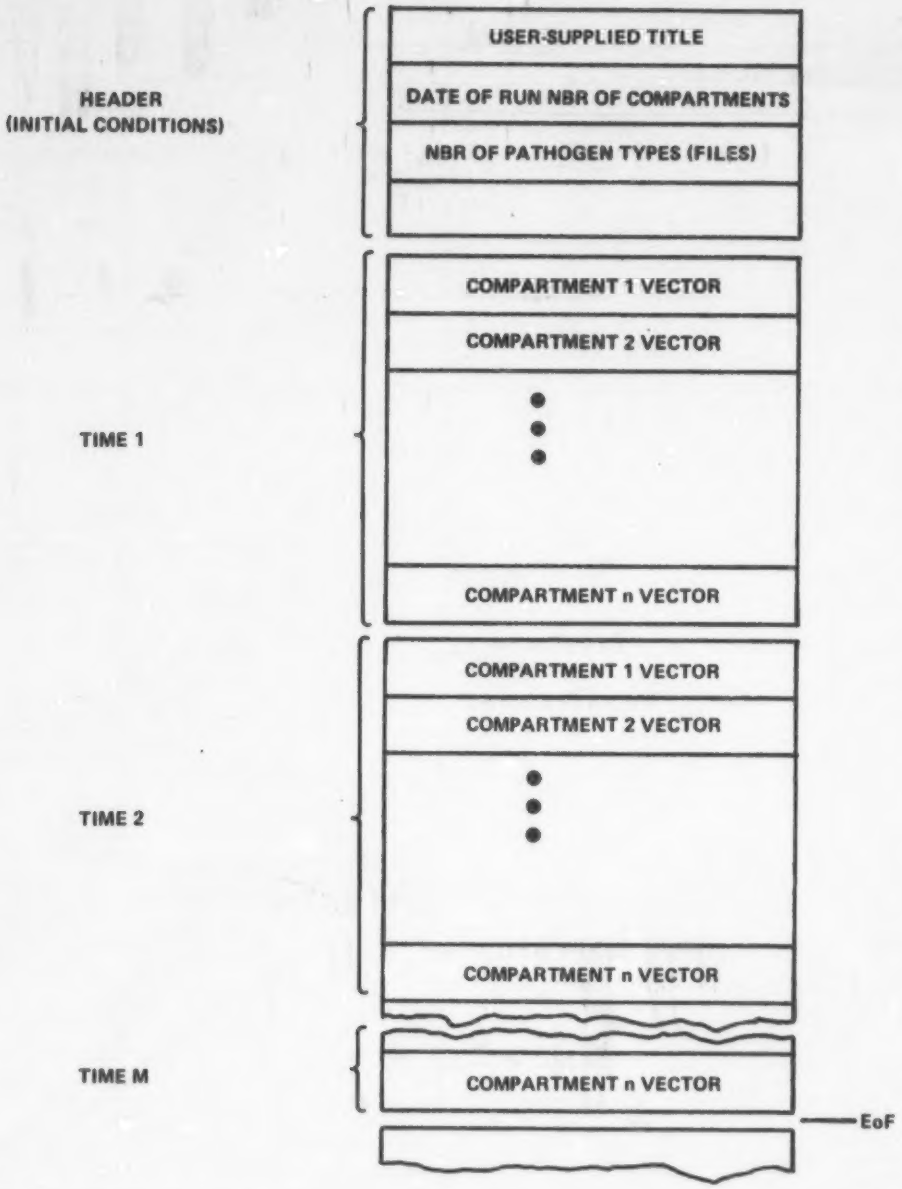
HEADER
(INITIAL CONDITIONS)
USER-SUPPLIED TITLE
DATE OF RUN NBR OF COMPARTMENTS
NBR OF PATHOGEN TYPES (FILES)
TIME 1
COMPARTMENT 1 VECTOR
COMPARTMENT 2 VECTOR
COMPARTMENT n VECTOR
TIME 2
COMPARTMENT 1 VECTOR
COMPARTMENT 2 VECTOR
COMPARTMENT n VECTOR
TIME M
COMPARTMENT n VECTOR
EoF

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Figure A-6. PTHOUT data structure.

A-6.

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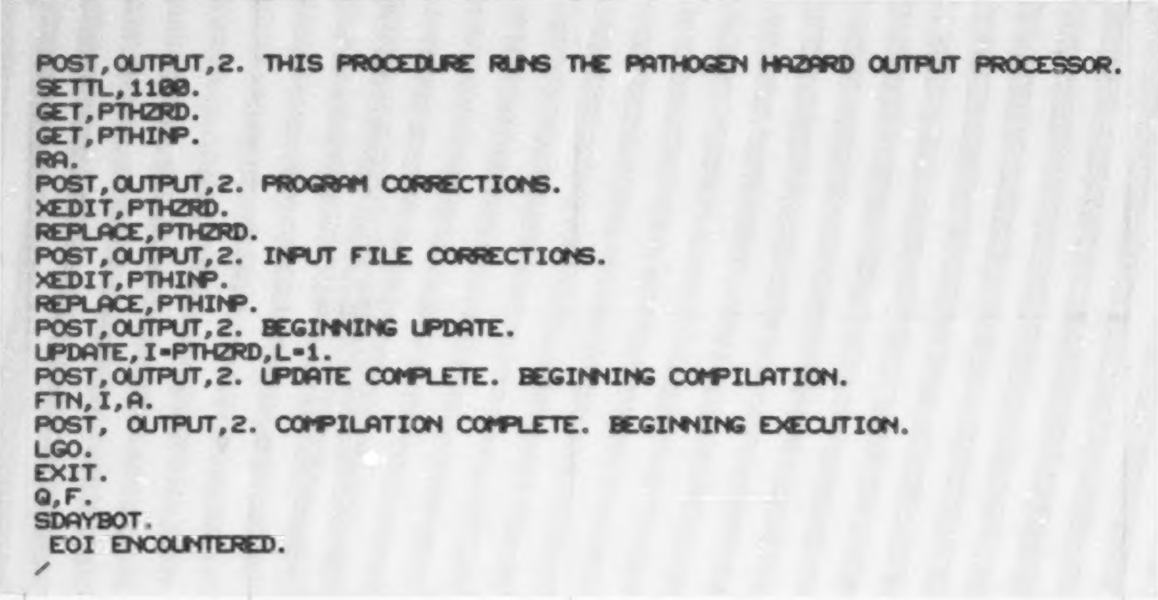

```
POST,OUTPUT,2. THIS PROCEDURE RUNS THE PATHOGEN HAZARD OUTPUT PROCESSOR.
SETTL,1100.
GET,PTHZRD.
GET,PTHINP.
RA.
POST,OUTPUT,2. PROGRAM CORRECTIONS.
XEDIT,PTHZRD.
REPLACE,PTHZRD.
POST,OUTPUT,2. INPUT FILE CORRECTIONS.
XEDIT,PTHINP.
REPLACE,PTHINP.
POST,OUTPUT,2. BEGINNING UPDATE.
UPDATE,I=PTHZRD,L=1.
POST,OUTPUT,2. UPDATE COMPLETE. BEGINNING COMPILATION.
FTN,I,A.
POST, OUTPUT,2. COMPILATION COMPLETE. BEGINNING EXECUTION.
LGO.
EXIT.
Q,F.
SDAYBOT.
 EOI ENCOUNTERED.
/
```

Figure A-7. PR procedure file - for debugging and executing the output processor.

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9-1/8"

TABLE A-5. PTHINP FILE STRUCTURE

CARD	LABEL	VARIABLES	DEFINITIONS
1	$FILES	NFILE = I	I ranges from 1 to 10 and indicates the number of files to process in PTHOUT. This could mean up to 10 different pathways with a particular pathogen or varying pathogen types.
	optional Default is ascending numeric order from 1 to N	IORDER (1) = I_1 IORDER (2) = I_2 . . .	I is the file number to be processed. Thus any file or any order of files from PTHOUT can be handled. N ranges from 1 to NFILE
2	$ICTRL	IDUMP default = 0	-1 → Do not dump file. 0 → Dump all compartments in file in ascending order. +1 → Dump only those compartments specified by IDSTAT array and in that order.
	optional	IDSTAT (1) = N_1 IDSTAT (2) = N_2 . . . IDSTAT (100) = N_{22}	Up to 100 compartments of a pathway can be dumped. The order is N_1, N_2, ... N_{100}

If IDUMP = 1, then there must be at least one IDSTAT value defined or nothing will be dumped but the headers.

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TABLE A-5 (Continued)

CARD	LABEL	VARIABLES	DEFINITIONS
		ISTATE default = 0	-1 → Do not print statistics. 0 → Print statistics for all compartments in this pathway. N → Print statistics for N compartments in the order specified by the ISTAT array for this pathway.
		ISTAT (1) = J_1 ISTAT (2) = J_2 . . . ISTAT (100) = J_{100}	Up to 100 states can be dumped from this pathway. The order is $J_1, J_2, \ldots, J_{100}$

If ISTATE = N, then there must be N values for ISTAT or nothing will be printed but the headers.

CARD	LABEL	VARIABLES	DEFINITIONS
		IPLOT default = 0	-1 → No plots. 0 → Plot those compartments which were specified by ISTATE.
		ISUPRS default = 0	When set greater than zero, this flag permits the statistics to be printed out with the plots; otherwise they are suppressed.
3	\$PLOT	This card exists only if IPLOT on card 2 is ≥ 0	
		ISIZE default = 0	

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TABLE A-5. (continued)

```
ISIZE  - SIZE OF ACTUAL PLOT AREA, NOT INCLUDING LABELS, ETC.
         IF =2, 4, 6, 8, 10, OR 12, THE PLOT SIZE WILL BE
            THAT MANY INCHES, HORIZONTALLY AND VERTICALLY.
          OR, ISIZE MAY BE OF THE FORM 100*IVERT+IHORZ, WHERE
            IVERT AND IHORZ ARE THE VERTICAL AND HORIZONTAL
            DIMENSIONS, IN INCHES, OF THE ACTUAL PLOT AREA.
            IN THIS CASE, IVERT AND IHORZ MUST EACH BE ONE OF
            THE VALUES 2, 4, 6, 8, 10, OR 12.
            WHEN USING A TERMINAL, IHORZ (OR ISIZE) SHOULD
            BE NO LARGER THAN 6.  WHEN USING A LINE PRINTER
            WITH AUTOMATIC PAGE EJECT AT PAGE BREAKS, IVERT
            (OR ISIZE) SHOULD BE NO LARGER THAN 8.
         IF ISIZE.LT.0, ITS FORM MUST BE- (100NROW+NCOL)
            WHERE NROW IS THE NUMBER OF ROWS OR PRINT LINES
            TO BE USED, AND NCOL IS THE NUMBER OF COLUMNS
            OR PRINT POSITIONS PER LINE.  THERE ARE NO
            RESTRICTIONS ON NROW AND NCOL EXCEPT THAT THEY
            BE AT LEAST TWO, AND NCOL.LE.121.
            FOR EXAMPLE, ISIZE= -49101 WOULD PRODUCE A 49 ROW
            BY 101 COLUMN (8 BY 10 INCH) PLOT.
            LABELING OF THE AXES MAY NOT APPEAR NICELY REGULAR
            WHEN UNUSUAL VALUES ARE USED FOR NROW OR NCOL.
         IF ISIZE=0, A 6 BY 6 INCH PLOT WILL BE DONE.
         IF ISIZE=1, AN 8 BY 8 INCH PLOT WILL BE DONE.
```

IPAGE default = -1

```
IPAGE  - IF  .GT.0, A PAGE EJECT WILL BE DONE BEFORE THE PLOT
             IS STARTED.
         IF  .LE.0, NO PAGE EJECT IS DONE.  THIS WOULD BE THE
             APPROPRIATE CHOICE FOR TERMINAL OUTPUT, OR IF
             YOU WISH TO PRINT A TITLE AT THE TOP OF THE PLOT.
```

IBOX default = -1

```
IBOX   - IF =1, A BOX WILL BE DRAWN (WITH ASTERISKS) AROUND
            THE ACTUAL PLOT AREA (NOT INCLUDING LABELS, ETC.)
            USE OF A BOX IS NOT RECOMMENDED WHEN USING A
            TERMINAL, AS IT MAY SLOW DOWN PLOTTING TOO MUCH.
         IF =2, THE BOX WILL BE DRAWN WITH PLUS SIGNS.
         IF =3, THE BOX WILL BE DRAWN WITH ZEROS.
         IF =4, THE BOX WILL BE DRAWN WITH THE LETTER X.
         IF .LE.0, NO BOX WILL BE DRAWN AROUND THE PLOT AREA.
```

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TABLE A-5. (continued)

ILABEL default = 1

```
ILABEL - IF =0 OR ANY VALUE OTHER THAN 1, 2, 3, OR 6, BOTH
            AXES WILL BE LABELLED EVERY TWO INCHES.
         IF =1, 2, 3, OR 6, THE Y AXIS WILL BE LABELLED EVERY
            WHOLE, HALF, THIRD, OR SIXTH OF AN INCH
            (ASSUMING SIX LINES ARE PRINTED PER VERTICAL INCH),
            WHILE THE X AXIS LABELLING REMAINS AT TWO INCHES.
         IF .LT.0, LABELS WILL BE SUPPRESSED COMPLETELY.
            HOWEVER, IF IMARK.GE.0, THE MAGNITUDE OF ILABEL
            WILL STILL INDICATE THE TIC MARK SPACING.
```

IMARK default = 0

6-1/2"

```
IMARK  - IF .GT.0, TIC MARKS WILL MARK EACH ROW OR COLUMN
            BEING LABELLED. THE LENGTHS OF THE MARKS WILL
            BE ROUGHLY IMARK/6 INCHES.  THUS, IF IMARK IS SET
            TO A LARGE NUMBER, SAY 100, THESE TIC MARKS WILL
            BECOME FULL GRID LINES.  NOTE -- THE X AXIS MAY
            NOT BE LABELLED MORE DENSELY THEN ONCE EVERY
            TWO INCHES.  HOWEVER, THE SPACING OF TIC MARKS
            ON THE X AXIS WILL EQUAL THAT OF THE Y AXIS
            EXCEPT WHEN IABS(ILABEL)=3 OR 6, IN WHICH CASE
            X AXIS TIC MARKS WILL REMAIN AT HALF INCH
            INTERVALS.
         IF .LT.0, NO TIC MARKS WILL BE USED.  IN THIS CASE,
            X AXIS LABELLING WILL BE SUPPRESSED, AS IT WOULD
            BE AMBIGUOUS.  THIS MODE MAY BE DESIRABLE WHEN
            PLOTTING HISTOGRAMS WITH ITYPE =2.
         IF =0, SINGLE CHARACTER MARKS WILL BE USED.
```

IAXES default = 1

```
IAXES  - IF .GT.0, X- AND Y- AXES WILL BE DRAWN ON THE PLOT, SO
            AS TO PASS AS CLOSELY AS POSSIBLE THROUGH X=0, Y=0.
         IF .LE.0, NO AXES WILL BE DRAWN.
```

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TABLE A-5. (continued)

ITYPE default = 1

```
ITYPE   - IF .LE.1, A NORMAL PLOT WILL BE DONE.
          IF =2, A HORIZONTAL BAR GRAPH WILL BE DRAWN.
             THIS MEANS THAT THE OCCURRENCE OF A DATA POINT
             ON A CURVE CAUSES THE PLOT CHARACTER FOR
             THAT CURVE TO BE PRINTED IN THE ROW/COLUMN
             POSITION INDICATED BY THAT POINT, PLUS IN ALL
             COLUMNS OF THAT ROW TO THE LEFT OF THAT POINT.
             HOWEVER, A HIGHER PRIORITY CURVE MAY THEN
             OVERPLOT SOME OR ALL OF THAT ROW OF CHARACTERS.
               SEE NOTE BELOW.
          IF .GE.3, A VERTICAL BAR GRAPH WILL BE DRAWN.
             THAT IS, A GIVEN POINT CAUSES ITS PLOT CHARACTER
             TO BE PLOTTED IN A GIVEN ROW/COLUMN POSITION,
             PLUS IN ALL ROWS BELOW THAT POSITION.
             HOWEVER, IF ANOTHER DATA POINT APPEARS LATER
             (I.E., LOWER) IN THIS COLUMN, IT WILL TAKE
             PRECEDENCE FOR THAT ROW AND BELOW.
               NOTE- YOU SHOULD NOT USE IMARK.GT.1 OR
                     IAXES.GT.0 WHEN ITYPE=3, AS ANYTHING
                     PRINTED ON THE ACTUAL PLOT AREA WILL
                     PROPAGATE BELOW THAT POINT JUST AS IF IT
                     WERE DATA.
```

RANGE (1) = 1.0
RANGE (2) = 0.0
RANGE (3) = Maximum X Value
RANGE (4) = 0.0
RANGE (5) = Maximum Y Value

```
RANGE   - IF RANGE=0, THE PLOT SCALES WILL BE DETERMINED BY
             THE DATA.  IN THIS CASE, THE MIDDLE OF THE FIRST
             COLUMN WILL CORRESPOND TO THE MINIMUM X VALUE,
             THE MIDDLE OF THE LAST COLUMN WILL CORRESPOND TO
             THE MAXIMUM X VALUE, THE MIDDLE OF THE BOTTOM ROW
             WILL CORRESPOND TO THE MINIMUM Y VALUE, AND THE
             MIDDLE OF THE TOP ROW WILL CORRESPOND TO THE
             MAXIMUM Y VALUE.
          IF RANGE.NE.0, THEN RANGE IS ASSUMED TO BE AN ARRAY
             OF LENGTH 5, CONTAINING THE FOLLOWING.
               RANGE(1) - A NON-ZERO VALUE.
               RANGE(2) - X VALUE OF LEFT-MOST COLUMN.
               RANGE(3) - X VALUE OF RIGHT- MOST COLUMN.
               RANGE(4) - Y VALUE OF BOTTOM ROW.
               RANGE(5) - Y VALUE OF TOP ROW.
             THESE RANGE PARAMETERS MAY BE USED EITHER TO
             EXTEND OR RESTRICT THE NORMAL RANGE.  THAT IS,
             THEY MAY BE USED TO ZOOM OUT OR IN.
```

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TABLE A-5 (concluded)

Note: Cards 3, 4, 5, and 6 must be repeated for each state of the pathway (file). Card 2 must be repeated for each pathway (file). If not repeated, the last value which was set will be used. If not present, the default values will be used.

CARD	LABEL	VARIABLES	DEFINITIONS
4	NONE	ITITLE (1) ITITLE (2) ITITLE (3)	30 Hollerith characters in columns 1 through 30 on the card used as a heading to the plot
5	NONE	IYAXIS (1) IYAXIS (2) default = POPULATION	20 Hollerith characters in columns 1 through 20 on the card. This is the Y-axis label.
6	NONE	IXAXIS (1) IXAXIS (2) default = TIME	20 Hollerith characters in columns 1 through 20 on the card. This is the X-axis label.

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TABLE A-6. PTHOUT DEFINITIONS

LINE	VARIABLES
1	LABEL - 40 Hollerith characters
2	LABEL - 40 Hollerith characters
3	LABEL - 40 Hollerith characters
4	Date: MM/DD/YY
5	Pathway Title - 40 Hollerith characters
6	Number of States (I2 Format) Pathogen Type - 30 Hollerith characters
7	Pathway Start Time (Hours) Relative Error Absolute Error Pathway Stop Time (Hours)
8	Pathway Classification Code Unused Pathogen Classification Code

Lines 9, 10, 11, etc. to the end of file. Each contains 10 words:

WORD NUMBER	DEFINITION
1	State Number
2	IFLAG value from ODE
3-7	Unused
8	Time (in hours) between integration steps
9	Time (in hours) of output of state
10	Population of state

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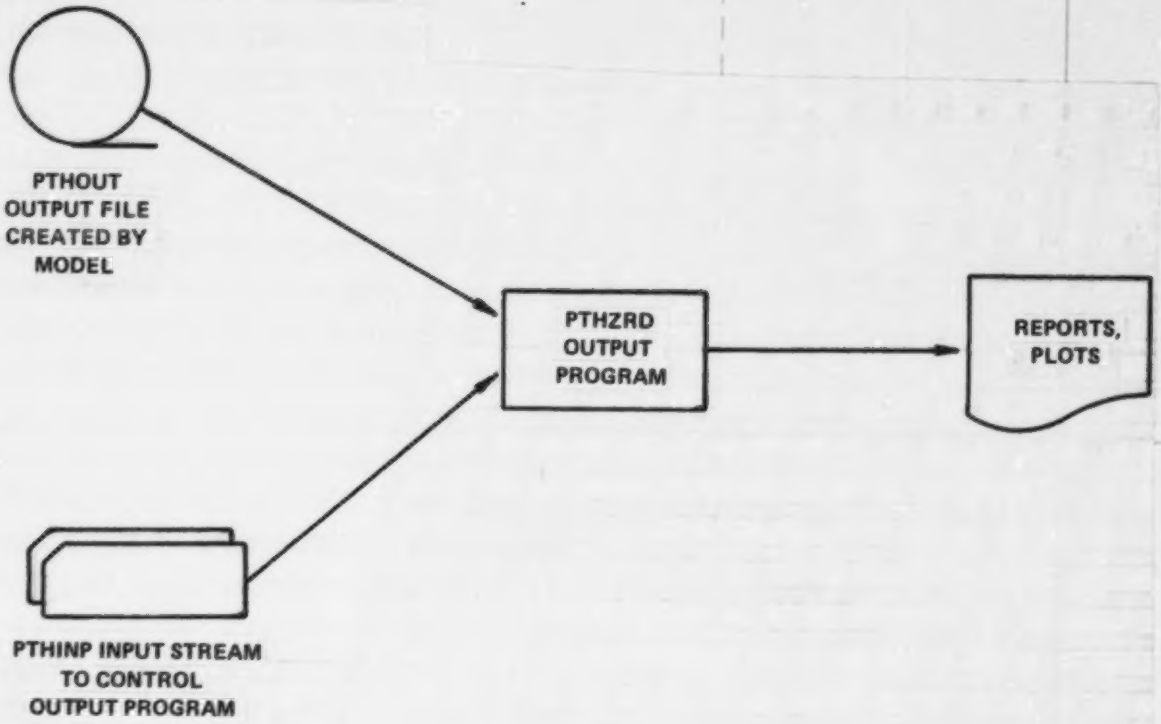
PTHOUT
OUTPUT FILE
CREATED BY
MODEL
PTHINP INPUT STREAM
TO CONTROL
OUTPUT PROGRAM
PTHZRD
OUTPUT
PROGRAM
REPORTS,
PLOTS

A-8
A-10.

Figure A-8. PTHZRD flow diagram.

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359F
500F

MODEL PROGRAMMER/ANALYST'S GUIDE

The Sewage Sludge Pathogen Transport Model (MODELS) is a user oriented code written in FORTRAN IV and developed under Sandia Laboratories' NOS/BE time-share operating system. It utilizes subroutines of the system's FXMATH Library to obtain the differential equation solver (ODE) and an input file created by the user (MDLIN2) to direct the model. The output capabilities include display on a CRT terminal screen or thermal printer, and creation of a BUFFER OUT file for postprocessing by the Output Processor and a local file (TAPE3) which can be dumped to a high-speed lineprinter. These output files contain initial input conditions, time steps, and populations of pathogens for each state of a pathway. (Figure A-9 illustrates the MODEL flow diagram.) The output may also contain transfer function values (TAU2), process function values (RHO2), and the parameter list (P array). When risk calculations are performed, the results are included in output.

The approach to the design phase of the model development was to use structured programming techniques so that any one particular pathway could be executed without having any other pathway subroutines in core. Thus as the model grew by the addition of pathways, the check-out and debug phase could be easily accomplished by compiling only those subroutines belonging to a particular pathway. In this way there would be no lengthy compilation of unnecessary routines and no problem with core limitations in a time-share environment. These characteristics far outweigh any duplication of code that has occurred because of similarities between pathways.

The top-down structure of the model is shown in Figure A-10 along with the subroutine naming conventions. The executive driver routine, called MODEL, contains the loop which calls ODE, the differential equation solver. ODE is documented in Sandia Laboratories report SAND77-1441, pages 5-6 to 5-7. At program load time, the BLOCK DATA subprogram initializes the default input variables for the model and its 13 pathways. Then the executive routine calls INIT, which is the executive driver for initializing user-supplied variables or changes to the default values for the model and the pathways. Depending on the pathway chosen, INIT will call a special initializing routine for that particular pathway. For example, if the user selects Pathway 4, then INIT4 is called by INIT to initialize its variables.

Once the pathway variables are initialized, the executive driver then loops on ODE which repetitively calls EVAL. EVAL is the executive driver for selecting the particular pathway evaluator drivers, labeled EVAL1 through EVAL13. The "T" or "A" appended to the name merely indicates whether this is a treatment or application pathway. EVAL1 through EVAL13

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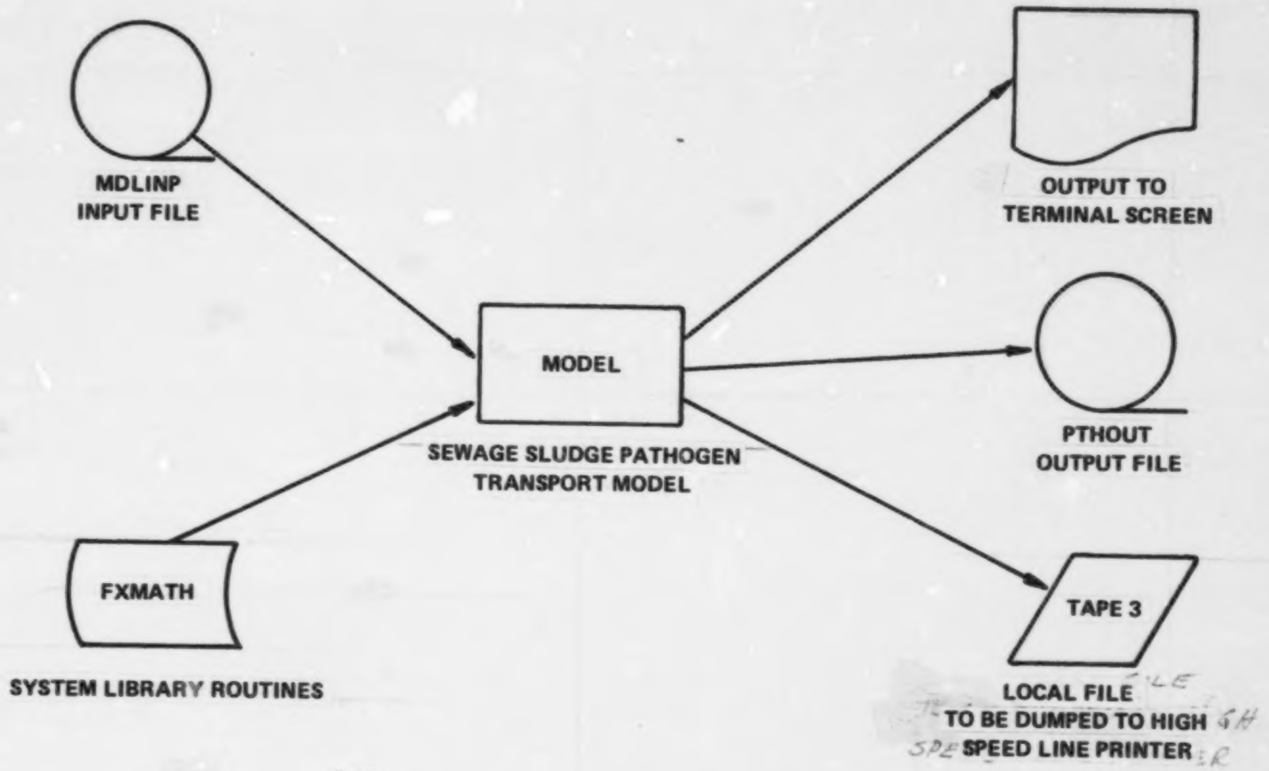
MDLINP
INPUT FILE
FXMATH
SYSTEM LIBRARY ROUTINES
MODEL
SEWAGE SLUDGE PATHOGEN
TRANSPORT MODEL
OUTPUT TO
TERMINAL SCREEN
PTHOUT
OUTPUT FILE
TAPE 3
LOCAL FILE
TO BE DUMPED TO HIGH
SPEED LINE PRINTER

A-9

Figure A-9. Sewage sludge pathogen transport program flow diagram.

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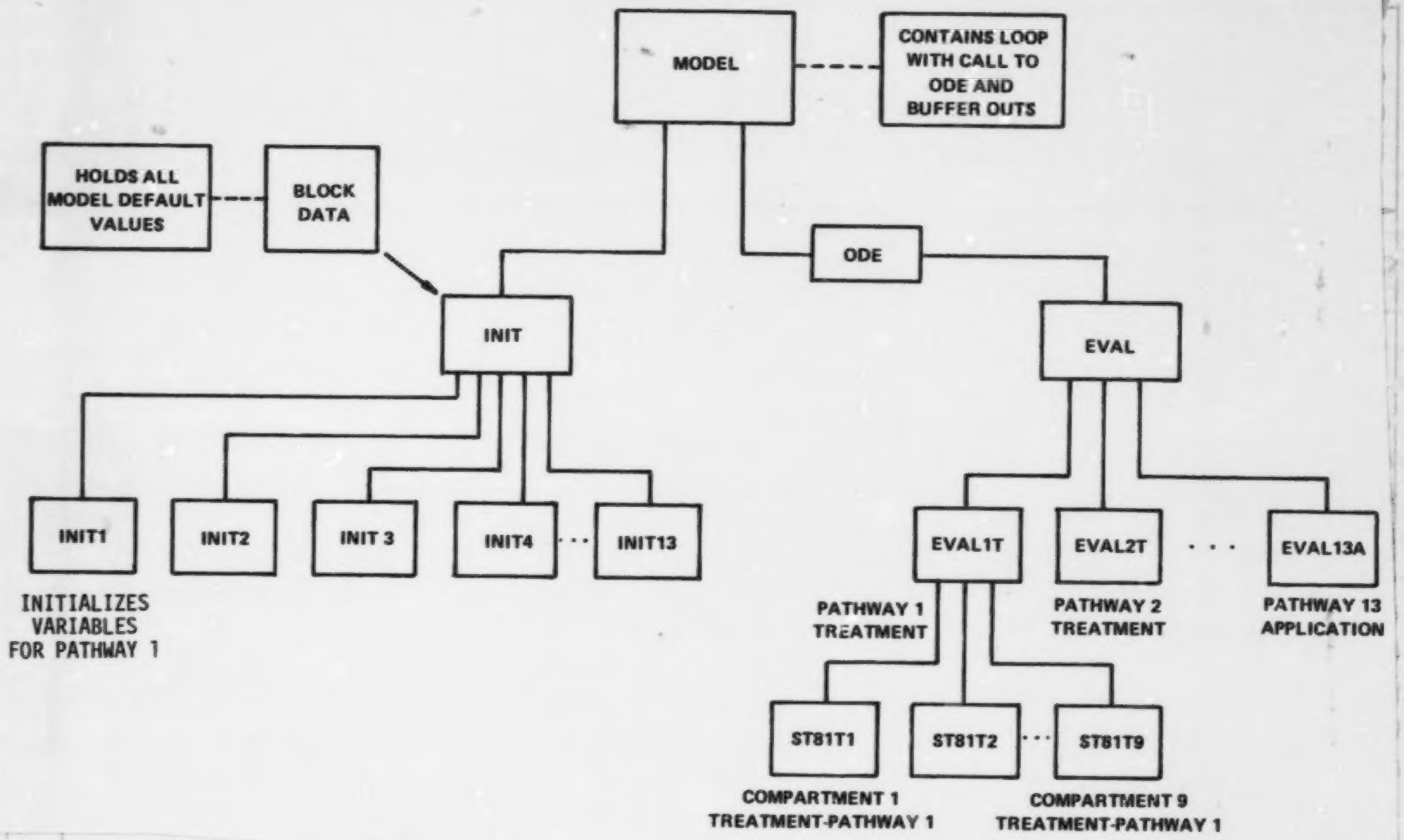
MODEL
CONTAINS LOOP WITH CALL TO ODE AND BUFFER OUTS
HOLDS ALL MODEL DEFAULT VALUES
BLOCK DATA
ODE
INIT
EVAL
INIT1
INIT2
INIT 3
INIT4
INIT13
INITIALIZES VARIABLES FOR PATHWAY 1
EVAL1T
EVAL2T
EVAL13A
PATHWAY 1 TREATMENT
PATHWAY 2 TREATMENT
PATHWAY 13 APPLICATION
ST81T1
ST81T2
ST81T9
COMPARTMENT 1 TREATMENT-PATHWAY 1
COMPARTMENT 9 TREATMENT-PATHWAY 1

Figure A-10. Model structure and subroutine naming conventions.

rotate 180°

are themselves drivers for calling the STATE routines which comprise the pathways and calculate the process and transfer functions RHOs and TAUs in the analyses. Figure A-11 illustrates an expanded view of the pathway code structure. The STATE subroutines all begin with the three characters "ST8" followed by the pathway number, a "T" or "A" for Treatment or Application, and then the compartment number. The compartment numbers can be found in Figures 1 through 13.

If NSTATS is not set to zero, the risk calculation driver, RISK, is called after ODE at each hour. The driver will call the appropriate risk calculation subroutine for each compartment specified in the ISTAT( ) array. The subroutines use the pathogen population in the specified compartments to calculate the risk to human health of ingesting airborne particulates, sewage sludge containing soil and residues, vegetables raised in amended soil and meat and milk from cows exposed to sludge or sludge containing feeds.

For making temporary code changes and for debugging purposes a procedure file was developed to expedite the process. The analyst can easily test a new code for inclusion in the model or modify the model by issuing the command:

```
CALL,MODLUP (Z=I)
```

Here "I" is the number of the pathway to be run. MODLUP is listed in Figure A-12. The files needed by this procedure plus all other files associated with the Sewage Sludge Pathogen Transport Model are stored as permanent files in 27BMCCL's disk area and are listed in Table A-7.

Finally, each compartment subroutine is described in Section 5 of this report. The exposure risk calculations are documented in Section 6.

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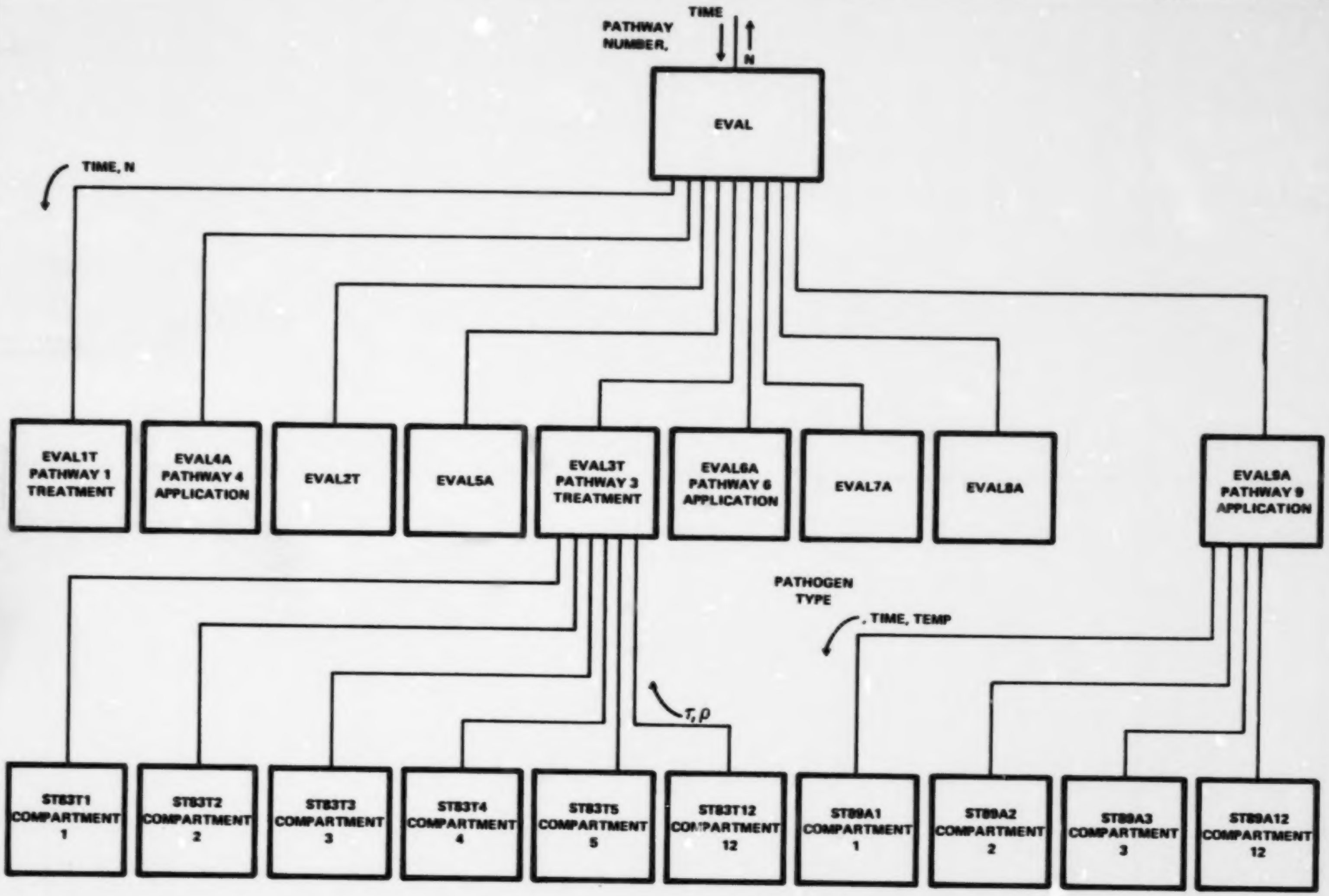
PATHWAY NUMBER,
TIME
N
EVAL
TIME, N
EVAL1T PATHWAY 1 TREATMENT
EVAL4A PATHWAY 4 APPLICATION
EVAL2T
EVAL5A
EVAL3T PATHWAY 3 TREATMENT
EVAL6A PATHWAY 6 APPLICATION
EVAL7A
EVAL8A
EVAL9A PATHWAY 9 APPLICATION
PATHOGEN TYPE
, TIME, TEMP
τ, ρ
ST83T1 COMPARTMENT 1
ST83T2 COMPARTMENT 2
ST83T3 COMPARTMENT 3
ST83T4 COMPARTMENT 4
ST83T5 COMPARTMENT 5
ST83T12 COMPARTMENT 12
ST89A1 COMPARTMENT 1
ST89A2 COMPARTMENT 2
ST89A3 COMPARTMENT 3
ST89A12 COMPARTMENT 12

Figure A-11. Naming conventions for subroutines.

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```
SETTL,1100.
CLEAR.
SET,R1=Z.
GET,MODELS.
GET,ODE1.
GET,ODE2.
IF(R1 .EQ. 1) GOTO,1BM.
IF(R1 .EQ. 2) GOTO,2BM.
IF(R1 .EQ. 3) GOTO,3BM.
IF(R1 .EQ. 4) GOTO,4BM.
IF(R1 .EQ. 5) GOTO,5BM.
IF(R1 .EQ. 6) GOTO,6BM.
IF(R1 .EQ. 7) GOTO,7BM.
IF(R1 .EQ. 8) GOTO,8BM.
IF(R1 .EQ. 9) GOTO,9BM.
IF(R1 .EQ. 10) GOTO,10BM.
IF(R1 .EQ. 11) GOTO,11BM.
IF(R1 .EQ. 12) GOTO,12BM.
IF(R1 .EQ. 13) GOTO,13BM.
GOTO,EXIT.
1BM,GET,MODELT=MODEL1.
GOTO,14BM.
2BM,GET,MODELT=MODEL2.
GOTO,14BM.
3BM,GET,MODELT=MODEL3.
GOTO,14BM.
4BM,GET,MODELT=MODEL4.
GOTO,14BM.
5BM,GET,MODELT=MODEL5.
GOTO,14BM.
6BM,GET,MODELT=MODEL6.
GOTO,14BM.
7BM,GET,MODELT=MODEL7.
GOTO,14BM.
8BM,GET,MODELT=MODEL8.
GOTO,14BM.
9BM,GET,MODELT=MODEL9.
GOTO,14BM.
10BM,GET,MODELT=MODEL10.
GOTO,14BM.
11BM,GET,MODELT=MODEL11.
GOTO,14BM.
12BM,GET,MODELT=MODEL12.
GOTO,14BM.
13BM,GET,MODELT=MODEL13.
14BM,REWIND,MODELT,MODELS.
COPYBF,MODELS,NEWMDL.
COPYBF,MODELT,NEWMDL.
PACK,NEWMDL.
REWIND,NEWMDL.
RETURN,MODELT,MODELS.
UPDATE,F,I=NEWMDL,N=NWMDL,L=1.
REWIND,NWMDL.
GET,UPDBM.
XEDIT,UPDBM.
REPLACE,UPDBM.
UPDATE,F,P=NWMDL,I=UPDBM,C=TEMPA,L=1.
RETURN,UPDBM.
POST,OUTPUT,4. UPDATE COMPLETED. BEGINNING FTN COMPILATION.
COPYBF,TEMPA,FRED.
COPYBF,ODE1,FRED.
COPYBF,ODE2,FRED.
PACK,FRED.
REWIND,FRED.
FTN,I=FRED.
POST,OUTPUT,4. FTN COMPILATION COMPLETED. BEGINNING LOAD.
RETURN,FRED,ODE1,ODE2.
REWIND,LGO.
GET,MDLIN2.
POST,OUTPUT,4. MAKE ANY LAST MINUTE PERMANENT CHANGES TO MDLIN2.
XEDIT,MDLIN2.
REPLACE,MDLIN2.
LDSET,PRESET=ZERO.
LDSET,MAP=SBEX/MDLMAP.
LGO.
EXIT.
END OF FILE.
```

A-12

Figure A-12. MOLDUP procedure file - for debugging the model.

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TABLE A-7. FILES ON MAGNETIC TAPE

MDLIN2 - Input file for the model.

MODELS - Source listing of those parts of the model pertaining to the 13 sludge treatment and application pathways including risk calculations.

MODEL1 through MODEL13 - Source listings of Pathways 1 through 13.

MODE1B through MODE9B
MOD10B through MOD13B - Relocatable binaries of those parts of the model necessary to execute Pathways 1 through 13.

MODLUP - Procedure file to debug and execute the model.

ODEBO - Relocatable binary of files ODE1 and ODE2.

ODE1 - First half of file containing subroutines of FXMATH library for implementing ODE.

ODE2 - Second half of file containing subroutines of FXMATH library for implementing ODE.

PR - Procedure file to debug and execute the output processor.

PTHGEN - Procedure file to execute the model.

PTHINP - Input file to control the output processor.

PTHLGO - Relocatable binary of the output processor.

PTHZRD - Output processor source listing.

UPD - Empty UPDATE input file correction set.

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EXAMPLES

The following sludge treatment and application scenarios are included to provide a step-by-step example of the use of the Sewage Sludge Pathogen Transport Model. The examples demonstrate the sequence of events involved in tailoring the scenario by specifying environmental parameters different from the default values contained in the model and selecting risk analysis for an environmental compartment. An excerpt from the output generated by the model is provided along with explanatory comments.

SCENARIO 1

This scenario describes the treatment of sludge as specified by Pathway 1 - General Sludge Treatment Pathway, depicted in Figure 1. Refer to Table 1b for definitions of the model variables associated with this pathway. The values of any variables not specifically mentioned below will be the default values shown in Table 1b.

Sludge entering a 30 MGD treatment plant contains 1×10^8 salmonella per kilogram of sludge (ASCRS = 1.0E8). The sludge is not anaerobically digested (ANAER = -1.) but is dried to 70 percent solids (PRSOL = default value) in a drying bed. The dried sludge is irradiated at a dose of 1 Mrad (DOSE = 1000.) and transported to an agricultural site. The risk will be determined for an individual standing 5 meters downwind from the drying bed and breathing airborne particulates generated from the drying bed (NSTATS = 1, ISTAT(1) =2, XDIST = 5., WINDSP = default value = 4.).

The following sequence of commands shown in Figure A-13 will lead to the execution of Pathway 1 under the conditions listed above. Model output will be sent to a line printer. A portion of the output from an actual model run is shown in Figure A-14.

SCENARIO 2

This scenario describes the application of dried sludge to a field used to grow vegetables for human consumption. Pathway 4, Sludge Application Pathway - Fertilizer for Crops Destined for Human Consumption (shown in Figure 4) is used. The variables used in this pathway and their default values are shown in Table 4b. Normally, the number of salmonella applied with the sludge would be the final population estimate in Compartment 8, at the end of a model run similar to the one described in Scenario 1. However, the megarad of irradiation, used as an example in Scenario 1, eliminated all of the salmonella.

In this case, the number of salmonella per kilogram of sludge entering the pathway will be set to 1×10^9 (ASCRS = 1.E9). An underground crop (CROP = -1.) will be grown in the field. The crop will be harvested 50 days after planting (THARV = 1200.). The default values provided in the model will be used for all other user-selectable variables.

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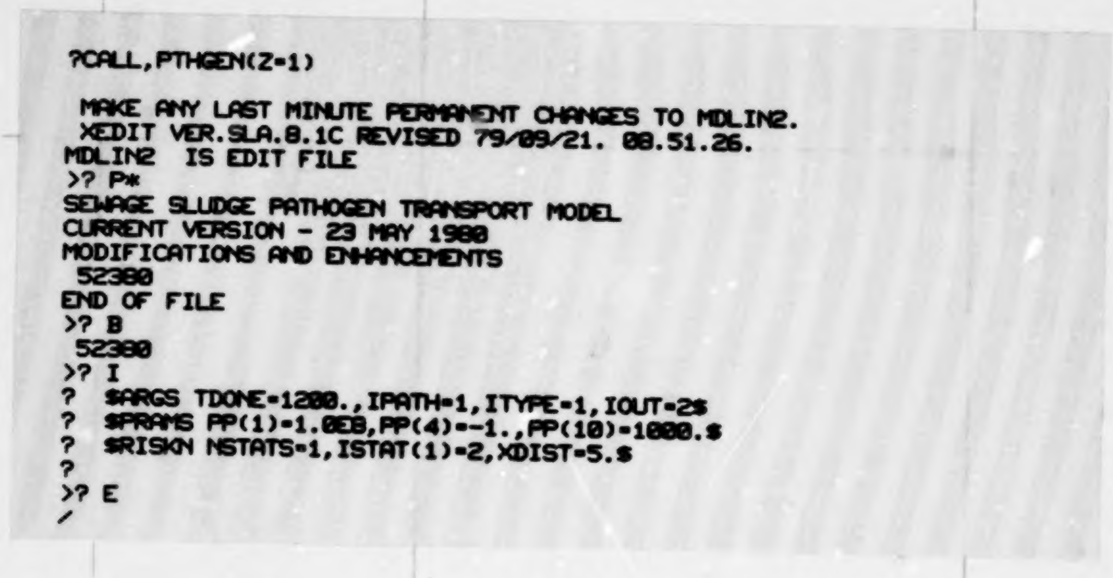

```
?CALL,PTHGEN(Z=1)

 MAKE ANY LAST MINUTE PERMANENT CHANGES TO MDLIN2.
 XEDIT VER.SLA.8.1C REVISED 79/09/21. 08.51.26.
MDLIN2  IS EDIT FILE
>? P*
SEWAGE SLUDGE PATHOGEN TRANSPORT MODEL
CURRENT VERSION - 23 MAY 1980
MODIFICATIONS AND ENHANCEMENTS
 52380
END OF FILE
>? B
 52380
>? I
?  $ARGS TDONE=1200.,IPATH=1,ITYPE=1,IOUT=2$
?  $PRAMS PP(1)=1.0E8,PP(4)=-1.,PP(10)=1000.$
?  $RISKN NSTATS=1,ISTAT(1)=2,XDIST=5.$
?
>? E
/
```

Figure A-13. Scenario 1 - input.

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```
  834.0    0.        0.        1.261E+10 0.        0.        0.        0.        0.        0.
  835.0    0.        0.        1.261E+10 0.        0.        0.        0.        0.        0.
  836.0    0.        0.        1.261E+10 0.        0.        0.        0.        0.        0.
  837.0    0.        0.        1.261E+10 0.        0.        0.        0.        0.        0.
  838.0    0.        0.        1.261E+10 0.        0.        0.        0.        0.        0.
  839.0    0.        0.        1.261E+10 0.        0.        0.        0.        0.        0.
  840.0    0.        0.        1.261E+10 0.        0.        0.        0.        0.        0.
  841.0    0.        0.        1.261E+10 0.        0.        0.        0.        0.        0.
  842.0    0.        0.        1.261E+10 0.        0.        0.        0.        0.        0.
  843.0    0.        0.        1.261E+10 0.        0.        0.        0.        0.        0.
  844.0    0.        0.        1.261E+10 0.        0.        0.        0.        0.        0.
  845.0    0.        0.        1.261E+10 0.        0.        0.        0.        0.        0.
  846.0    0.        0.        1.261E+10 0.        0.        0.        0.        0.        0.
  847.0    0.        0.        1.261E+10 0.        0.        0.        0.        0.        0.
  848.0    0.        0.        1.261E+10 0.        0.        0.        0.        0.        0.
  849.0    0.        0.        1.261E+10 0.        0.        0.        0.        0.        0.
  850.0    0.        0.        1.261E+10 0.        0.        0.        0.        0.        0.
  851.0    0.        0.        1.261E+10 0.        0.        0.        0.        0.        0.
  852.0    0.        0.        1.261E+10 0.        0.        0.        0.        0.        0.
  853.0    0.        0.        1.261E+10 0.        0.        0.        0.        0.        0.
  854.0    0.        0.        1.261E+10 0.        0.        0.        0.        0.        0.
  855.0    0.        0.        1.261E+10 0.        0.        0.        0.        0.        0.
  856.0    0.        0.        1.261E+10 0.        0.        0.        0.        0.        0.
  857.0    0.        0.        1.261E+10 0.        0.        0.        0.        0.        0.
  858.0    0.        0.        1.261E+10 0.        0.        0.        0.        0.        0.
  859.0    0.        0.        1.261E+10 0.        0.        0.        0.        0.        0.
  860.0    0.        9.563E+04 4.638E+09 7.148E+05 1.205E+03 5.583E+09 0.        0.        0.
 FOR COMPARTMENT   2 AN INFECTIOUS DOSE IS INHALED .5E+01METERS FROM A FARTICULATE SOURCE AFTER   .5562E+02 MINUTES
  861.0    0.        1.135E+05 2.130E+09 1.959E+06 6.657E+03 4.623E+09 0.        0.        0.
 FOR COMPARTMENT   2 AN INFECTIOUS DOSE IS INHALED .5E+01METERS FROM A FARTICULATE SOURCE AFTER   .6446E+02 MINUTES
  862.0    0.        7.165E+04 2.129E+09 2.057E+06 1.006E+04 2.429E+09 0.        0.        0.
 FOR COMPARTMENT   2 AN INFECTIOUS DOSE IS INHALED .5E+01METERS FROM A FARTICULATE SOURCE AFTER   .7424E+02 MINUTES
  863.0    0.        4.523E+04 2.129E+09 1.299E+06 1.186E+04 1.281E+09 0.        0.        0.
 FOR COMPARTMENT   2 AN INFECTIOUS DOSE IS INHALED .5E+01METERS FROM A FARTICULATE SOURCE AFTER   .1176E+03 MINUTES
  864.0    0.        2.859E+04 2.129E+09 8.199E+05 1.280E+04 6.758E+08 0.        0.        0.
 FOR COMPARTMENT   2 AN INFECTIOUS DOSE IS INHALED .5E+01METERS FROM A FARTICULATE SOURCE AFTER   .1863E+03 MINUTES
  865.0    0.        1.803E+04 2.129E+09 5.176E+05 1.330E+04 3.565E+08 0.        0.        0.
 FOR COMPARTMENT   2 AN INFECTIOUS DOSE IS INHALED .5E+01METERS FROM A FARTICULATE SOURCE AFTER   .2951E+03 MINUTES
  866.0    0.        1.138E+04 2.129E+09 3.267E+05 1.357E+04 1.861E+08 0.        0.        0.
 FOR COMPARTMENT   2 AN INFECTIOUS DOSE IS INHALED .5E+01METERS FROM A FARTICULATE SOURCE AFTER   .4674E+03 MINUTES
  867.0    0.        7.183E+03 2.129E+09 2.063E+05 1.370E+04 9.922E+07 0.        0.        0.
 FOR COMPARTMENT   2 AN INFECTIOUS DOSE IS INHALED .5E+01METERS FROM A FARTICULATE SOURCE AFTER   .7424E+03 MINUTES
  868.0    0.        4.535E+03 2.129E+09 1.302E+05 1.376E+04 5.234E+07 0.        0.        0.
 FOR COMPARTMENT   2 AN INFECTIOUS DOSE IS INHALED .5E+01METERS FROM A FARTICULATE SOURCE AFTER   .1173E+04 MINUTES
  869.0    0.        2.863E+03 2.129E+09 8.220E+04 1.382E+04 2.761E+07 0.        0.        0.
 FOR COMPARTMENT   2 AN INFECTIOUS DOSE IS INHALED .5E+01METERS FROM A FARTICULATE SOURCE AFTER   .1858E+04 MINUTES
  870.0    0.        1.807E+03 2.129E+09 5.189E+04 1.384E+04 1.457E+07 0.        0.        0.
 FOR COMPARTMENT   2 AN INFECTIOUS DOSE IS INHALED .5E+01METERS FROM A FARTICULATE SOURCE AFTER   .2943E+04 MINUTES
  871.0    0.        1.141E+03 2.129E+09 3.276E+04 1.385E+04 7.685E+06 0.        0.        0.
 FOR COMPARTMENT   2 AN INFECTIOUS DOSE IS INHALED .5E+01METERS FROM A FARTICULATE SOURCE AFTER   .4662E+04 MINUTES
  872.0    0.        7.202E+02 2.129E+09 2.068E+04 1.385E+04 4.054E+06 0.        0.        0.
 FOR COMPARTMENT   2 AN INFECTIOUS DOSE IS INHALED .5E+01METERS FROM A FARTICULATE SOURCE AFTER   .7365E+04 MINUTES
  873.0    0.        4.546E+02 2.129E+09 1.306E+04 1.386E+04 2.139E+06 0.        0.        0.
 FOR COMPARTMENT   2 AN INFECTIOUS DOSE IS INHALED .5E+01METERS FROM A FARTICULATE SOURCE AFTER   .1170E+05 MINUTES
  874.0    0.        2.870E+02 2.129E+09 8.242E+03 1.386E+04 1.128E+06 0.        0.        0.
 FOR COMPARTMENT   2 AN INFECTIOUS DOSE IS INHALED .5E+01METERS FROM A FARTICULATE SOURCE AFTER   .1853E+05 MINUTES
  875.0    0.        1.812E+02 2.129E+09 5.203E+03 1.386E+04 5.952E+05 0.        0.        0.
 FOR COMPARTMENT   2 AN INFECTIOUS DOSE IS INHALED .5E+01METERS FROM A FARTICULATE SOURCE AFTER   .2936E+05 MINUTES
  876.0    0.        1.144E+02 2.129E+09 3.284E+03 1.386E+04 3.140E+05 0.        0.        0.
 FOR COMPARTMENT   2 AN INFECTIOUS DOSE IS INHALED .5E+01METERS FROM A FARTICULATE SOURCE AFTER   .4650E+05 MINUTES
  877.0    0.        7.221E+01 2.129E+09 2.073E+03 1.386E+04 1.656E+05 0.        0.        0.
 FOR COMPARTMENT   2 AN INFECTIOUS DOSE IS INHALED .5E+01METERS FROM A FARTICULATE SOURCE AFTER   .7366E+05 MINUTES
  878.0    0.        4.558E+01 2.129E+09 1.309E+03 1.386E+04 8.738E+04 0.        0.        0.
 FOR COMPARTMENT   2 AN INFECTIOUS DOSE IS INHALED .5E+01METERS FROM A FARTICULATE SOURCE AFTER   .1167E+06 MINUTES
```

Figure A-14. Scenario 1 - Selected segment of output showing time between 834 and 878 hours into pathway.

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Risk will be examined for Compartment 5 and Compartment 13 (NSTATS = 2, ISTAT(1) = 5, ISTAT(2) = 13). The risk output for Compartment 5 (SOIL SURFACE) will show the amount of soil that would have to be ingested to provide an infectious dose with salmonella at any point in time. The risk output for Compartment 13 (COMMERCIAL CROP) will estimate the number of carrots that would carry an infectious dose of salmonella at the time of harvest. The risk portion of the scenario will be modified so that the carrots are consumed raw, immediately after harvest, but are washed (ISTRH = 0.0, IWASH = 1. (default value), IBLAN = 0.0, ICANC = 0.0, ISTRP = 0.0, ICOOK = 0.0). The definitions for the variables associated with the exposure risk calculations in this scenario are found in Table 15 in Section 6 of this volume.

The sequence of commands shown in Figure A-15 will lead to the execution of Pathway 4 under the conditions listed above. Model output will be sent to the line printer. A portion of the output from an actual model run is shown in Figure A-16.

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```
?CALL,PTHGEN(Z=4)

 MAKE ANY LAST MINUTE PERMANENT CHANGES TO MDLIN2.
 XEDIT VER.SLA.8.1C REVISED 79/09/21. 08.51.26.
MDLIN2  IS EDIT FILE
>? P*
SEWAGE SLUDGE PATHOGEN TRANSPORT MODEL
CURRENT VERSION - 23 MAY 1980
MODIFICATIONS AND ENHANCEMENTS
 52380
END OF FILE
>? B
 52380
>? I
?  $ARGS TDONE=1240.,IPATH=4,ITYPE=1,IOUT=2$
?  $PRAMS PP(1)=1.0E9,PP(12)=1200.,PP(15)=-1.$
?  $RISKN NSTATS=2,ISTAT(1)=5,ISTAT(2)=13,ISTRH=0,IBLAN=0,ICANG=0,
   ISTRP=0,ICOOK=0$
?
>? E
/
```

Figure A-15. Scenario 2 - Input.

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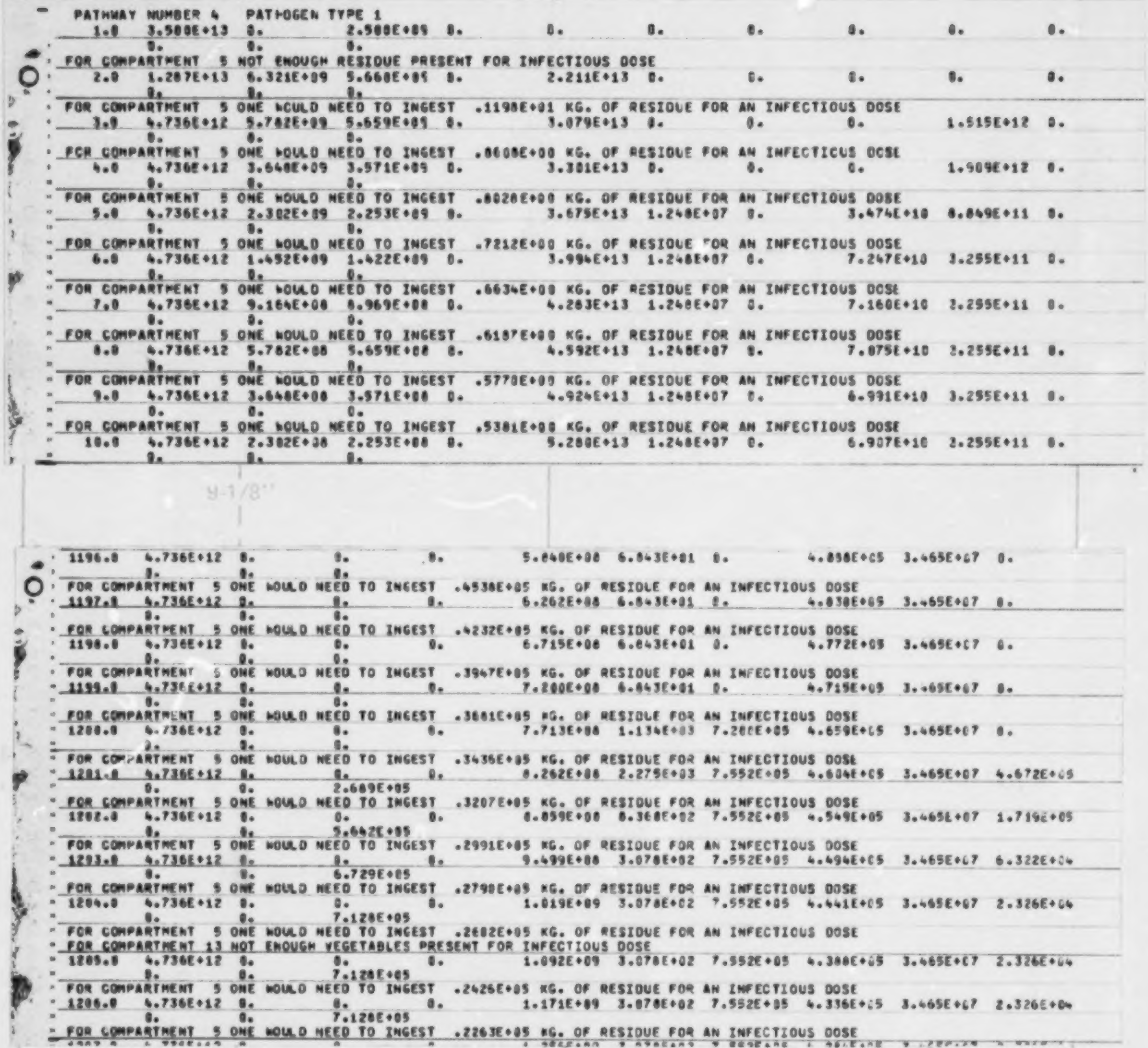

```
  PATHWAY NUMBER 4   PATHOGEN TYPE 1
      1.0   3.500E+13  0.         2.500E+09  0.         0.         0.         0.         0.         0.         0.
            0.         0.         0.
 FOR COMPARTMENT  5 NOT ENOUGH RESIDUE PRESENT FOR INFECTIOUS DOSE
      2.0   1.207E+13  6.321E+09  5.660E+05  0.         2.211E+13  0.         0.         0.         0.         0.
            0.         0.         0.
 FOR COMPARTMENT  5 ONE WOULD NEED TO INGEST  .1198E+01 KG. OF RESIDUE FOR AN INFECTIOUS DOSE
      3.0   4.736E+12  5.782E+09  5.659E+09  0.         3.079E+13  0.         0.         0.         1.515E+12  0.
            0.         0.         0.
 FOR COMPARTMENT  5 ONE WOULD NEED TO INGEST  .8608E+00 KG. OF RESIDUE FOR AN INFECTICUS DOSE
      4.0   4.736E+12  3.648E+09  3.571E+09  0.         3.381E+13  0.         0.         0.         1.909E+12  0.
            0.         0.         0.
 FOR COMPARTMENT  5 ONE WOULD NEED TO INGEST  .8028E+00 KG. OF RESIDUE FOR AN INFECTIOUS DOSE
      5.0   4.736E+12  2.302E+09  2.253E+09  0.         3.675E+13  1.240E+07  0.         3.474E+10  8.049E+11  0.
            0.         0.         0.
 FOR COMPARTMENT  5 ONE WOULD NEED TO INGEST  .7212E+00 KG. OF RESIDUE FOR AN INFECTIOUS DOSE
      6.0   4.736E+12  1.452E+09  1.422E+09  0.         3.994E+13  1.240E+07  0.         7.247E+10  3.255E+11  0.
            0.         0.         0.
 FOR COMPARTMENT  5 ONE WOULD NEED TO INGEST  .6634E+00 KG. OF RESIDUE FOR AN INFECTIOUS DOSE
      7.0   4.736E+12  9.164E+08  8.969E+08  0.         4.283E+13  1.240E+07  0.         7.160E+10  3.255E+11  0.
            0.         0.         0.
 FOR COMPARTMENT  5 ONE WOULD NEED TO INGEST  .6187E+00 KG. OF RESIDUE FOR AN INFECTIOUS DOSE
      8.0   4.736E+12  5.782E+08  5.659E+08  0.         4.592E+13  1.240E+07  0.         7.075E+10  3.255E+11  0.
            0.         0.         0.
 FOR COMPARTMENT  5 ONE WOULD NEED TO INGEST  .5770E+00 KG. OF RESIDUE FOR AN INFECTIOUS DOSE
      9.0   4.736E+12  3.648E+08  3.571E+08  0.         4.924E+13  1.240E+07  0.         6.991E+10  3.255E+11  0.
            0.         0.         0.
 FOR COMPARTMENT  5 ONE WOULD NEED TO INGEST  .5381E+00 KG. OF RESIDUE FOR AN INFECTIOUS DOSE
     10.0   4.736E+12  2.302E+08  2.253E+08  0.         5.280E+13  1.240E+07  0.         6.907E+10  3.255E+11  0.
            0.         0.         0.
```

```
 1196.0    4.736E+12  0.         0.         0.         5.840E+08  6.843E+01  0.         4.888E+05  3.465E+07  0.
           0.         0.         0.
 FOR COMPARTMENT  5 ONE WOULD NEED TO INGEST  .4530E+05 KG. OF RESIDUE FOR AN INFECTIOUS DOSE
 1197.0    4.736E+12  0.         0.         0.         6.262E+08  6.843E+01  0.         4.830E+05  3.465E+07  0.
           0.         0.         0.
 FOR COMPARTMENT  5 ONE WOULD NEED TO INGEST  .4232E+05 KG. OF RESIDUE FOR AN INFECTIOUS DOSE
 1198.0    4.736E+12  0.         0.         0.         6.715E+08  6.843E+01  0.         4.772E+05  3.465E+07  0.
           0.         0.         0.
 FOR COMPARTMENT  5 ONE WOULD NEED TO INGEST  .3947E+05 KG. OF RESIDUE FOR AN INFECTIOUS DOSE
 1199.0    4.736E+12  0.         0.         0.         7.200E+08  6.843E+01  0.         4.715E+05  3.465E+07  0.
           0.         0.         0.
 FOR COMPARTMENT  5 ONE WOULD NEED TO INGEST  .3681E+05 KG. OF RESIDUE FOR AN INFECTIOUS DOSE
 1200.0    4.736E+12  0.         0.         0.         7.713E+08  1.134E+03  7.200E+05  4.659E+05  3.465E+07  0.
           0.         0.         0.
 FOR COMPARTMENT  5 ONE WOULD NEED TO INGEST  .3436E+05 KG. OF RESIDUE FOR AN INFECTIOUS DOSE
 1201.0    4.736E+12  0.         0.         0.         8.262E+08  2.275E+03  7.552E+05  4.604E+05  3.465E+07  4.672E+05
           0.         0.         2.689E+05
 FOR COMPARTMENT  5 ONE WOULD NEED TO INGEST  .3207E+05 KG. OF RESIDUE FOR AN INFECTIOUS DOSE
 1202.0    4.736E+12  0.         0.         0.         8.859E+08  8.368E+02  7.552E+05  4.549E+05  3.465E+07  1.719E+05
           0.         0.         5.642E+05
 FOR COMPARTMENT  5 ONE WOULD NEED TO INGEST  .2991E+05 KG. OF RESIDUE FOR AN INFECTIOUS DOSE
 1203.0    4.736E+12  0.         0.         0.         9.499E+08  3.078E+02  7.552E+05  4.494E+05  3.465E+07  6.322E+04
           0.         0.         6.729E+05
 FOR COMPARTMENT  5 ONE WOULD NEED TO INGEST  .2790E+05 KG. OF RESIDUE FOR AN INFECTIOUS DOSE
 1204.0    4.736E+12  0.         0.         0.         1.019E+09  3.078E+02  7.552E+05  4.441E+05  3.465E+07  2.326E+04
           0.         0.         7.128E+05
 FOR COMPARTMENT  5 ONE WOULD NEED TO INGEST  .2602E+05 KG. OF RESIDUE FOR AN INFECTIOUS DOSE
 FOR COMPARTMENT 13 NOT ENOUGH VEGETABLES PRESENT FOR INFECTIOUS DOSE
 1205.0    4.736E+12  0.         0.         0.         1.092E+09  3.078E+02  7.552E+05  4.388E+05  3.465E+07  2.326E+04
           0.         0.         7.128E+05
 FOR COMPARTMENT  5 ONE WOULD NEED TO INGEST  .2426E+05 KG. OF RESIDUE FOR AN INFECTIOUS DOSE
 1206.0    4.736E+12  0.         0.         0.         1.171E+09  3.078E+02  7.552E+05  4.336E+05  3.465E+07  2.326E+04
           0.         0.         7.128E+05
 FOR COMPARTMENT  5 ONE WOULD NEED TO INGEST  .2263E+05 KG. OF RESIDUE FOR AN INFECTIOUS DOSE
```

Figure A-16. Scenario 2 - Selected segments of output showing the first 10 hours of the pathway run and the time of harvest.

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APPENDIX B

SEWAGE SLUDGE PATHOGEN TRANSPORT MODEL PROJECT

LIBRARY STORAGE AND RETRIEVAL PROGRAMS

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(PREVIOUSLY CIN. EPA FORM 287)
☆ U.S. GOVERNMENT PRINTING OFFICE 1980-660-639
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ABSTRACT

Library Storage and Retrieval Programs were developed to assist in managing abstracts of reviewed literature collected to support the Sewage Sludge Pathogen Transport Model. The programs are written in FORTRAN IV for execution on the Sandia Laboratories CDC computer system under NOS. They use a standardized literature review form to organize information for storage. The form is displayed on a Tektronix 4025 terminal, and the user types the abstract and index information onto the form. The index information, which includes the title of the publication, the principal author, the source (periodical title, etc.) and a set of keywords, is used to retrieve the stored abstract. The keywords which are currently part of the programs were selected for the Sewage Sludge Pathogen Transport Model, but the storage and retrieval programs are designed to accommodate any keyword list developed to index a particular data base. The programs will return listings of information in storage by author, title, source, or keyword, and will print out a partial or complete literature review form of any stored item.

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SECTION B-1

INTRODUCTION

The Library Storage and Retrieval Programs described in this volume were designed to organize and store a comprehensive data base from which computer models decribing the fate of pathogens during sewage sludge treatment and application were developed. The data base is composed of abstracts of reviewed literature which were first entered on printed library review forms (LRF) (Figure B-1). These forms provided for the classification of articles by author, title, source, and subject matter using a list of descriptive keywords. In addition, the forms provide a format for entering abstracts into a computerized library data base (LDB) using the Library Storage Program which produces a replica of the printed form on a Tektronix 4025 computer display terminal.

The list of keywords used to classify each abstract by subject matter is the basis for retrieving information for use in computer model development. Keywords form the communication link between the storage and retrieval programs. Because of their pivotal role in communicating between the programs and because of the literal way in which the parameters are processed by the computer, the keywords are rigidly formatted and strict rules were followed in their creation and use. The list of valid keywords is presented in Table B-1. Both the Library Storage Program and the Library Retrieval Program were intentionally designed to be very flexible and can be modified by an experienced programmer to accomodate a different set of keywords suitable for classifying another data base.

The use of the Library Storage and Retrieval Programs throughout the project has emphasized both the importance of thoughtful selection of keywords during data base design and the need for care when choosing particular keywords to classify an article. It has been evident that for efficient use of a computerized data base, consideration of projected retrieval procedures while selecting keywords is as important as choosing keywords which accurately reflect article contents.

Standard abbreviations are used in entering the source of a journal article on the library review form (LRF). Again, decisions concerning the manner of abbreviation reflect the requirements of the project for which the Library Storage and Retrieval Programs were developed. Another system of source entry could be used in the construction of a new data base as long as the rules regarding character and length limitations (explained more fully in Section 2) are not violated.

The standard abbreviations presented in the American Chemical Society's 1974 edition of BIBLIOGRAPHIC GUIDE FOR EDITORS AND AUTHORS were

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Principal Author:
Other Authors:

Title:

Source:
Other Source Info:

Keywords:

A. Emphasis: Review___ Survival___ Sludgtrait___ Treatment___ Disposal___ Modeling___
Pathman___ Pathanimal___ Pathplant___ Other___
B. Pathogens: Bacteria___ Ecoli___ Leptospira___ Mycobact___ Salmonella___ Shigella___ Virus___
Adenovirus___ CoxsackieA___ CoxsackieB___ Echovirus___ Hepatitis___
Poliovirus___ Reovirus___ Rotavirus___ Parasite___ Protozoa___ Entamoeba___
Giardia___ Helminths___ Ascaris___ Cestodes___ Taenia___ Hymenolep___
Echinococ___ Fungi___ Other___
C. Origin: Municipal___ Domestic___ Other___
D. Treatment: None___ Anaerobic___ Aerobic___ Chemical___ Heat___ Compost___ Lagooning___
HighpH___ Dewatering___ Radiation___ Storage___ Drying___ Other___
E. Sludgeuse: Irrigation___ Flow___ Spray___ Injection___ Foodcrop___ Forage___ Landispose___
Feed___ Gardening___ Other___
F. Hazard: Virulence___ Immunity___ Contact___ Other___
G. Transport: Percolation___ Runoff___ Airborne___ Crops___ Insect___ Other___
H. Soiltrait: pH___ CEC___ Soiltype___ Toxichem___ Other___
I. Modeling: Model___ Simulation___ Transfers___ Other___

Abstract:

Figure B-1. Library review form.

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TABLE B-1. KEYWORDS VALID IN PATHOGEN HAZARD LIBRARY STORAGE AND RETRIEVAL PROGRAMS

EMPHASIS	(REVIEW)	PATHOGENS	(HELMINTHS)	SLUDGEUSE	(INJECTION)
"	(SURVIVAL)	"	(ASCARIS)	"	(FOODCROP)
"	(SLUDGTRAIT)	"	(CESTODES)	"	(FORAGE)
"	(TREATMENT)	"	(TAENIA)	"	(LANDISPOSE)
"	(DISPOSAL)	"	(HYMENOLEP)	"	(FEED)
"	(MODELING)	"	(ECHINOCOC)	"	(GARDENING)
"	(PATHMAN)	"	(FUNGI)	"	(OTHER)
"	(PATHANIMAL)	"	(OTHER)		
"	(PATHPLANT)			HAZARD	(VIRULENCE)
"	(OTHER)	ORIGIN	(MUNICIPAL)	"	(IMMUNITY)
		"	(DOMESTIC)	"	(CONTACT)
PATHOGENS	(BACTERIA)	"	(OTHER)	"	(OTHER)
"	(ECOLI)				
"	(LEPTOSPIRA)	TREATMENT	(NONE)	TRANSPORT	(PERCOLATE)
"	(MYCOBACT)	"	(ANAEROBIC)	"	(RUNOFF)
"	(SALMONELLA)	"	(AEROBIC)	"	(AIRBORNE)
"	(SHIGELLA)	"	(CHEMICAL)	"	(CROPS)
"	(VIRUS)	"	(HEAT)	"	(INSECT)
"	(ADENOVIRUS)	"	(COMPOST)	"	(OTHER)
"	(COXSACKIEA)	"	(LAGOONING)		
"	(COXSACKIEB)	"	(HIGHPH)	SOILTRAIT	(PH)
"	(ECHOVIRUS)	"	(DEWATERING)	"	(CEC)
"	(HEPATITIS)	"	(RADIATION)	"	(SOILTYPE)
"	(POLIOVIRUS)	"	(STORAGE)	"	(TOXICHEM)
"	(REOVIRUS)	"	(DRYING)	"	(OTHER)
"	(ROTAVIRUS)	"	(OTHER)		
"	(PARASITE)			MODELING	(MODEL)
"	(PROTOZOA)	SLUDGEUSE	(IRRIGATE)	"	(SIMULATION)
"	(ENTAMOEBA)	"	(FLOW)	"	(TRANSFERS)
"	(GIARDIA)	"	(SPRAY)	"	(OTHER)

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used to abbreviate most journal names. The following general rules were applied. Single-word names were not abbreviated but written out in full within the 20-character limit of the source field. Each word of multiword names was abbreviated according to the listing in the bibliographic guide, and then as much of the name entered as possible within the 20-character limit. For example, the abbreviation for APPLIED AND ENVIRONMENTAL MICROBIOLOGY would be Appl Environ Microbiol. Each word in the title can be found in the alphabetical listing of terms in the Bibliographic Guide. Prepositions such as "of" and "for", conjunctions such as "and", and articles such as "a" and "the" are neither separately abbreviated nor included in the final abbreviation of the title. The standard abbreviation of the example (Appl Environ Microbiol) contains 22 characters including the spaces between each word but excluding periods and other punctuation marks which may not be used in the searchable fields of the Library Storage Program. The standard abbreviation is shortened to 20 characters by removing the last two characters in the last abbreviated word of the title. "Microbiol" becomes "Microbi" and the abbreviation for APPLIED AND ENVIRONMENTAL MICROBIOLOGY becomes Appl Environ Microbi. This abbreviation was used when entering the abstracts of articles published in APPLIED AND ENVIRONMENTAL MICROBIOLOGY. A listing of some of the more common words found in journal names and the standard abbreviation for each is presented in Table B-2.

Table B-2 is an alphabetical list of some of the more common words used in periodical titles of interest to this project. No attempt has been made to reproduce the extensive list published in the BIBLIOGRAPHIC GUIDE FOR EDITORS AND AUTHORS to which the reader is referred.

The BIBLIOGRAPHIC GUIDE FOR EDITORS AND AUTHORS lists foreign language periodicals as well as English language publications. The abbreviation of a Russian, German, French, Spanish, or Swedish periodical title may be constructed as easily as one for an English title by locating each word separately in the listing and stringing the standard abbreviations together. An example: the abbreviation of the title of the German periodical ZENTRALBLATT FUER BAKTERIOLOGIE is Zentralbl Bakteriol.

Five exceptions were made to the use of abbreviations derived by the rules given. The following journal names or parts of names are abbreviated as shown:

American Society of Civil Engineers = ASCE
International Atomic Energy Association = IAEA
Journal of the American Water Works Associations = JAWWA
Journal of the Water Pollution Control Federation = JWPCF
World Health Organization = WHO

These are abbreviations in common usage and were used to conserve file space and permit more information to be entered in the source field.

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TABLE B-2. ABBREVIATIONS OF WORDS COMMONLY FOUND IN JOURNAL TITLES

A
Annuals = Ann
Annual = Annu
Applied = Appl
Association = Assoc

B
Bacteria = Bacter
Bacteriology = Bacteriol
Biochemistry = Biochem
Biology = Biol
Biophysics = Biophys
British = Br
Bulletin = Bull

C
Candian = Can
Cell = Cell
Chemi(stry)(cal) = Chem
Civil = Civ
Clinical = Clin
Communication = Commun
Comparative = Compar
Compost = Compost
Contamination = Contam
Control = Control
Critical = Crit

D
Dairy = Dairy
Department = Dept
Developments = Dev
Diseases = Dis
Division = Div
Drainage = Drain

E
Ecology = Ecol
Engineering = Eng
Entomolog(y)(ist)(ical) = Entomol
Epidemiology = Epidemiol

F
Federa(l)(tion) = Fed
Forest(ry) = For
Food = Food

G
General = Gen

H
Health = Health
Hygiene = Hyg

I
Immun(ity)(ology) = Immun
Indust(y)(ial) = Ind
Infect(ion)(ious) = Infect
Internal = Intern
Irrigation = Irrig

J
Japan(ese) = Jpn
Journal = J

K

L
Laboratory = Lab

M
Management = Man
Marine = Mar
Medic(ine)(al) = Med
Microbiolog(y)(ical) = Microbiol
Molecul(e)(ar) = Mol

N
National = Natl
New England = N Engl

O
Organization = Org

P
Parasitology = Parsit
Pathology = Pathol
Plant = Plant
Pollution = Pollut
Proceeding = Pro
Production = Prod
Protection = Protect
Public = Pub

Q
Quality = Qual

R
Radiation = Radiat
Record = Rec
Report = Rept
Research = Res

S
Scandinavi(an)(a) = Scand
Science = Sci
Series = Ser
Sewage = Sew
Society = Soc
Soil = Soil

T
Technology = Technol
Toxicology = Toxicol
Tropical = Trop

U

V
Veterinary = Vet
Virology = Virol

W
Waste = Waste
Water = Water
Wildlife = Wildl
Works = Works

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SECTION B-2

LIBRARY STORAGE PROGRAM USER'S GUIDE

STORAGE PROGRAM CAPABILITIES

The Library Storage Program is written in FORTRAN IV for execution on the Sandia Laboratories CDC Computer System under NOS. The program accepts input data via a Tektronix 4025 terminal and stores the data in a library review form (LRF) master file. A system overview of the storage program is illustrated in Figure B-2. As shown, the program is an on-line system in which LRF data are viewed from a terminal located at a remote site.

The primary purpose of the storage program is to build a library data base (LDB) consisting of user-entered LRF data. After all LRF data for a session have been entered, the LDB is saved on a file that can be linked to the Library Retrieval Program for LRF searches or relinked to the storage program for adding more LRF data. The storage program can only add new LRF data to the LDB. That is, for this release of the storage program a LDB cannot be updated by changing or deleting LRF data.

LIBRARY REVIEW FORM DATA BASE STRUCTURE

The design philosophy behind building an LRF data base was both to collect LRF data and to link the collected LRFs to one another through common LRF attributes. These common attributes have been identified as author names, keyword names, and source names. A fourth, unique attribute, LRF title, was also identified. Structuring the data base as an attribute-linked list allows one to seek LRF information by multiple common attributes as well as by a single common attribute. An example of the type of query for which this structure is well suited is

"Find all LRFs for author John Wall"

Another example of the data base query capability is

"Find all LRFs for author John Wall where keyword Salmonella exists"

By allowing an LRF to point to another LRF with the same attribute, queries like those above can easily "thread" LRFs together. This threaded list allows for efficient processing of subsets of records with common attributes. Figure B-3 illustrates the threading process for the first query given above. In this example only two LRFs were found to have the author John Wall. The last occurrence of this author contains an unused pointer field in the author record which is a null entry. Note that each LRF may have up to 82 keyword links as well as a source and author link.

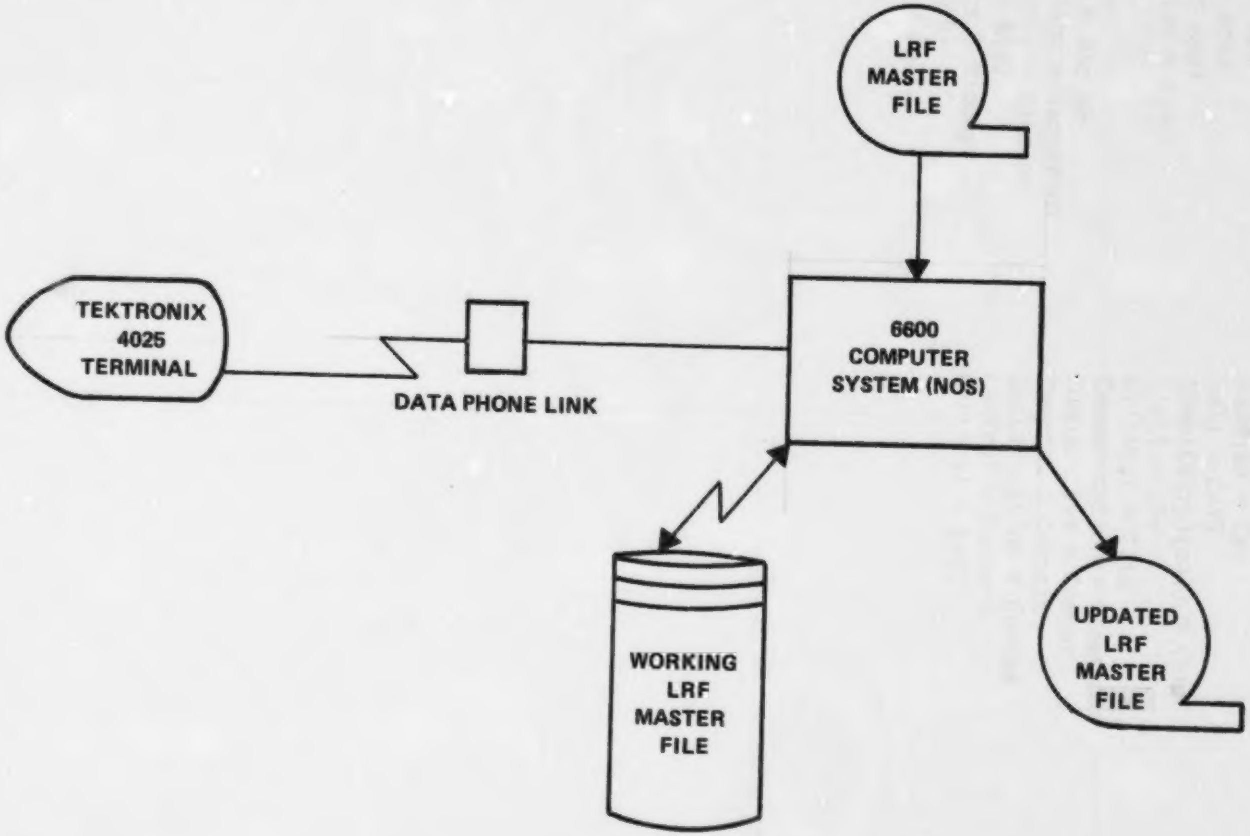
LRF MASTER FILE
6600 COMPUTER SYSTEM (NOS)
UPDATED LRF MASTER FILE
WORKING LRF MASTER FILE
TEKTRONIX 4025 TERMINAL
DATA PHONE LINK

Figure B-2. Library support program system overview.

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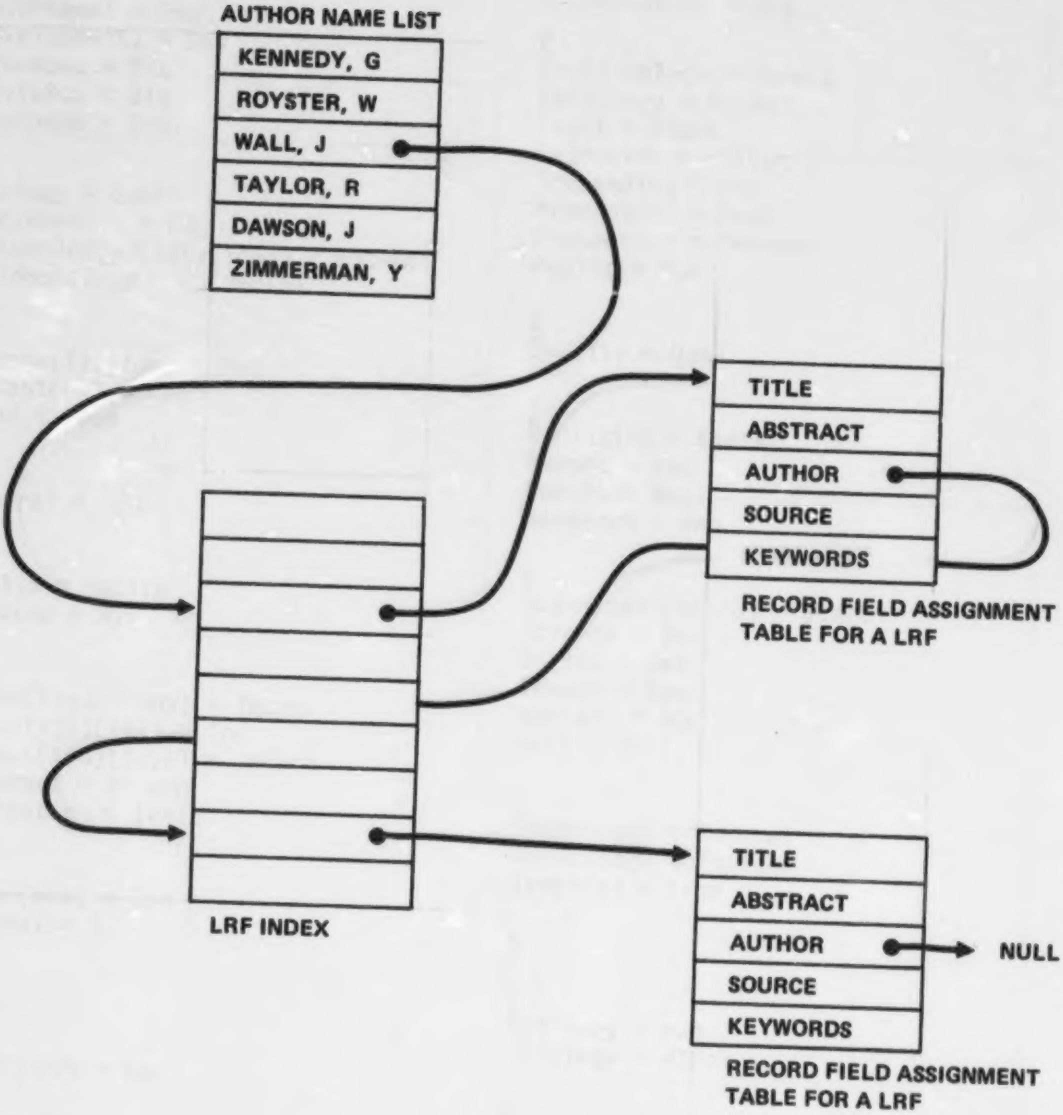

AUTHOR NAME LIST
KENNEDY, G
ROYSTER, W
WALL, J
TAYLOR, R
DAWSON, J
ZIMMERMAN, Y
TITLE
ABSTRACT
AUTHOR
SOURCE
KEYWORDS
RECORD FIELD ASSIGNMENT TABLE FOR A LRF
LRF INDEX
TITLE
ABSTRACT
AUTHOR
NULL
SOURCE
KEYWORDS
RECORD FIELD ASSIGNMENT TABLE FOR A LRF

Figure B-3. Threaded list for an author.

Once an LRF data base has been built, it may be saved as a file on the CDC computer system. To add another LRF, the existing LRF data base is simply linked to the LRF storage program and the new LRF is entered on a remote terminal. The storage program will perform all the bookkeeping requirements necessary to update the threaded list for each common attribute of each new LRF. Likewise, if one wishes to query the existing LRF data base, then the query program is linked to the LRF data base and the user queries the data for information via the query commands discussed in Section 4.

INPUT DATA STRUCTURE

The LDB structure provides the user with a system to enter LRF data into an attribute-linked data base. The storage program is further enhanced by using the form-fill-out mode option of the Tektronix 4025. This capability and user instructions for use in updating the LDB are discussed in the following subsections.

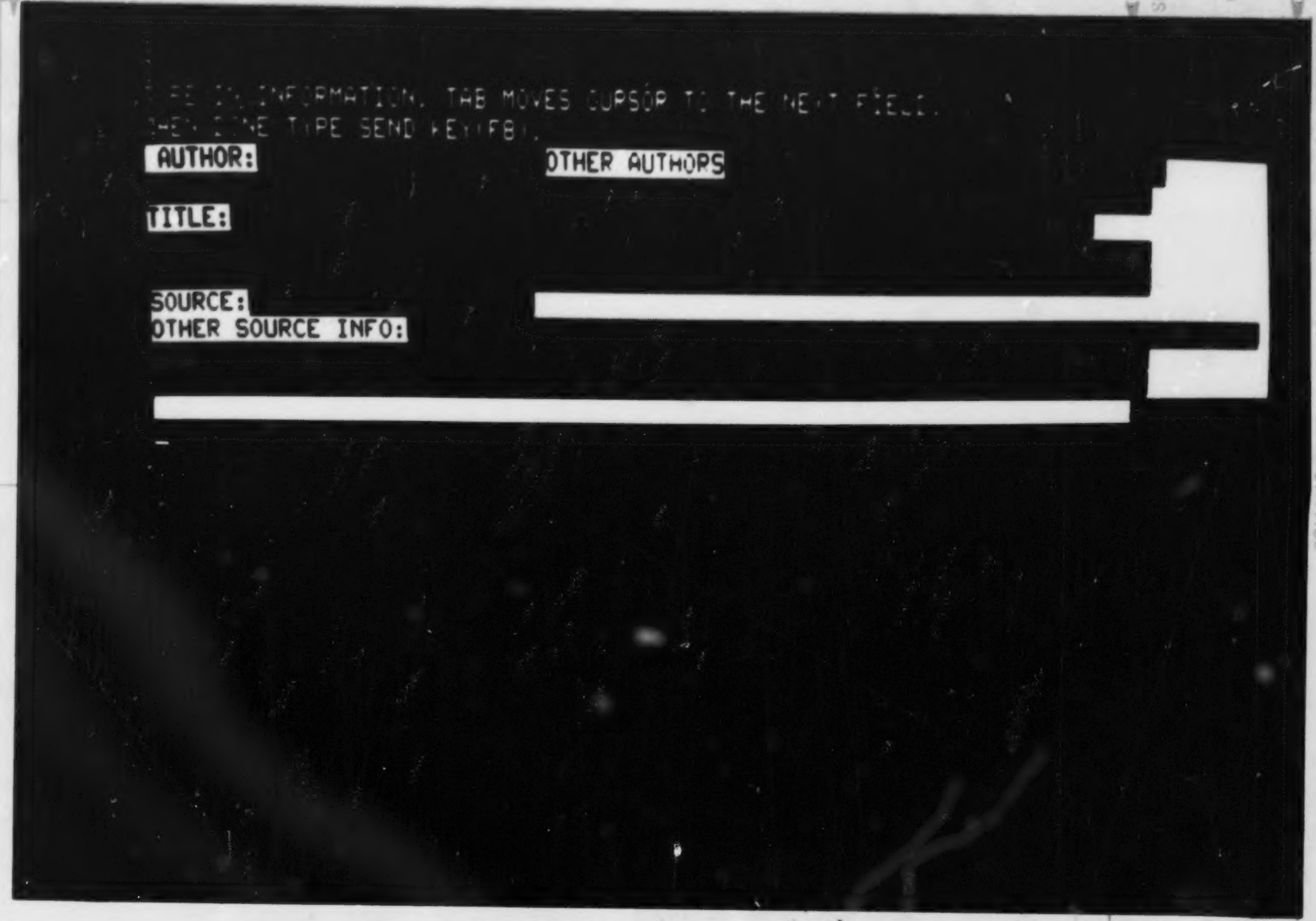
LRF Forms Processing

In order to enter the large number of LRFs into the LDB, a FORTRAN routine was developed to provide for user LRF data input from a Tektronix 4025 terminal. This terminal has several features which enhance LRF data entry capability. One of these features is a buffered mode of operation in which the Tektronix 4025 is programmed to transmit in lines of text rather than one line of characters. Another feature allows the user to pre-edit the LRF data lines before sending LRF data to the host computer. These features are accomplished by using the form-fill-out mode available on this terminal. The storage program generates an LRF image on the terminal screen by sending Tektronix 4025 commands. The user fills in each blank field of the form on the screen with corresponding data from an LRF.

The forms processor presents the user with an LRF in three sections. Two of these sections are shown in Figures B-4 and B-5. After the user has completed a section, the information may be edited before transmission to the host computer. Even after a section has been transmitted, the user has the option of reentering the entire section. Only after all three sections have been received by the host computer will the working LRF master file be updated with the new LRF information. An additional feature of the form-fill-out option is that the program prevents the user from exceeding the maximum character length allocated to each LRF data field. Once an LRF data field is full, the screen cursor will automatically tab to the next LRF data field. If the user does not wish to enter any data into an LRF data field, the field may be skipped by simply pressing the TAB key. The tab feature allows the user to keep track of the cursor position on the LRF.

The use of the Tektronix 4025 terminal allows for a data entry system design that not only greatly increases the ease and speed of information storage, but reduces the potential for user error during the LRF data entry process.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER

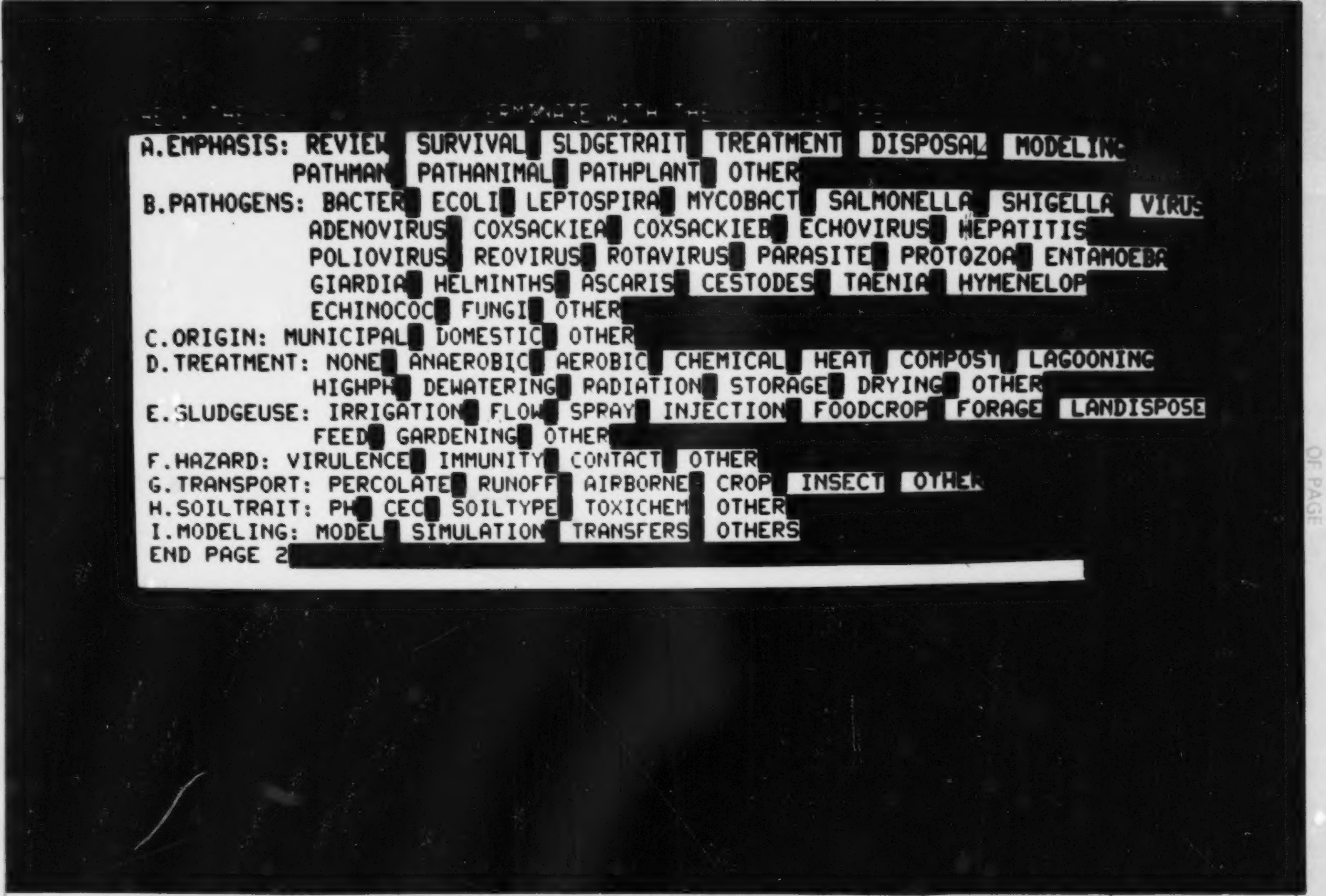


```
TYPE IN INFORMATION. TAB MOVES CURSOR TO THE NEXT FIELD.
WHEN DONE TYPE SEND KEY(F8).
 AUTHOR:                              OTHER AUTHORS

TITLE:


SOURCE:
OTHER SOURCE INFO:
```

Figure B-4. Tektronix 4025 display for Literature Review Form Section 1.



```
A.EMPHASIS: REVIEW SURVIVAL SLDGETRAIT TREATMENT DISPOSAL MODELING
          PATHMAN PATHANIMAL PATHPLANT OTHER
B.PATHOGENS: BACTER ECOLI LEPTOSPIRA MYCOBACT SALMONELLA SHIGELLA VIRUS
           ADENOVIRUS COXSACKIEA COXSACKIEB ECHOVIRUS HEPATITIS
           POLIOVIRUS REOVIRUS ROTAVIRUS PARASITE PROTOZOA ENTAMOEBA
           GIARDIA HELMINTHS ASCARIS CESTODES TAENIA HYMENELOP
           ECHINOCOC FUNGI OTHER
C.ORIGIN: MUNICIPAL DOMESTIC OTHER
D.TREATMENT: NONE ANAEROBIC AEROBIC CHEMICAL HEAT COMPOST LAGOONING
           HIGHPH DEWATERING RADIATION STORAGE DRYING OTHER
E.SLUDGEUSE: IRRIGATION FLOW SPRAY INJECTION FOODCROP FORAGE LANDISPOSE
           FEED GARDENING OTHER
F.HAZARD: VIRULENCE IMMUNITY CONTACT OTHER
G.TRANSPORT: PERCOLATE RUNOFF AIRBORNE CROP INSECT OTHER
H.SOILTRAIT: PH CEC SOILTYPE TOXICHEM OTHER
I.MODELING: MODEL SIMULATION TRANSFERS OTHERS
END PAGE 2
```

Figure B-5. Tektronix 4025 display for Literature Review Form Section 2.

BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"
PAGE NUMBER

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Creating/Modifying the LDB

The user of the storage program must be aware of two external files required to create and modify the LDB. These files are known to the storage program as OLDLRF and NEWLRF. The structures of these files are described in the next subsection. The file OLDLRF contains an LDB created during an earlier run of the storage program. However, if a new or first-time LDB file is being created, OLDLRF will be empty. The storage program recognizes an OLDLRF empty file and will respond with:

```
**WARNING-MASTER DATA BASE FILE (OLDLRF) EMPTY**
         NEW DATA BASE WILL BE CREATED
    DO YOU WISH TO CONTINUE?  (1=YES; 0=NO)
```

The user should respond with a 1 if the LRF data inputs are to be part of the new LDB. Of course, a 0 answer should be replied when the user wants to update an existing LDB but forgot to "get" it. To update an existing LDB the user should use the following NOS command prior to loading the storage program:

```
GET, OLDLRF = username
```

Once the storage program is loaded on the CDC computer system the program is ready to accept LRF data. These data are input using the form-fill-out mode as described in the previous section. After the abstract of a LRF has been entered and terminated with a dollar ($) sign, the storage program will respond with:

```
DO YOU WISH TO ENTER ANOTHER NEW LRF?  (1=YES; 0=NO)
```

The user should respond with 0 if the last LRF has been entered. A "NO" answer will result in normal termination of the storage program. At this time the user should save the LDB created or modified by using the NOS REPLACE or SAVE command by the following:

```
REPLACE, username = NEWLRF
```

or

```
SAVE, username = NEWLRF
```

The LDB is now ready for computerized searches on selected keywords using the retrieval program or may be updated to include new LRF data.

OUTPUT DATA STRUCTURE

The storage program output consists of an LDB sequential file. This section discusses the output format, structure, and file access/save procedures.

LDB Sequential File

The LDB is maintained on a sequential file following a storage program data entry session. The file is written using the CDC FORTRAN IV BUFFER

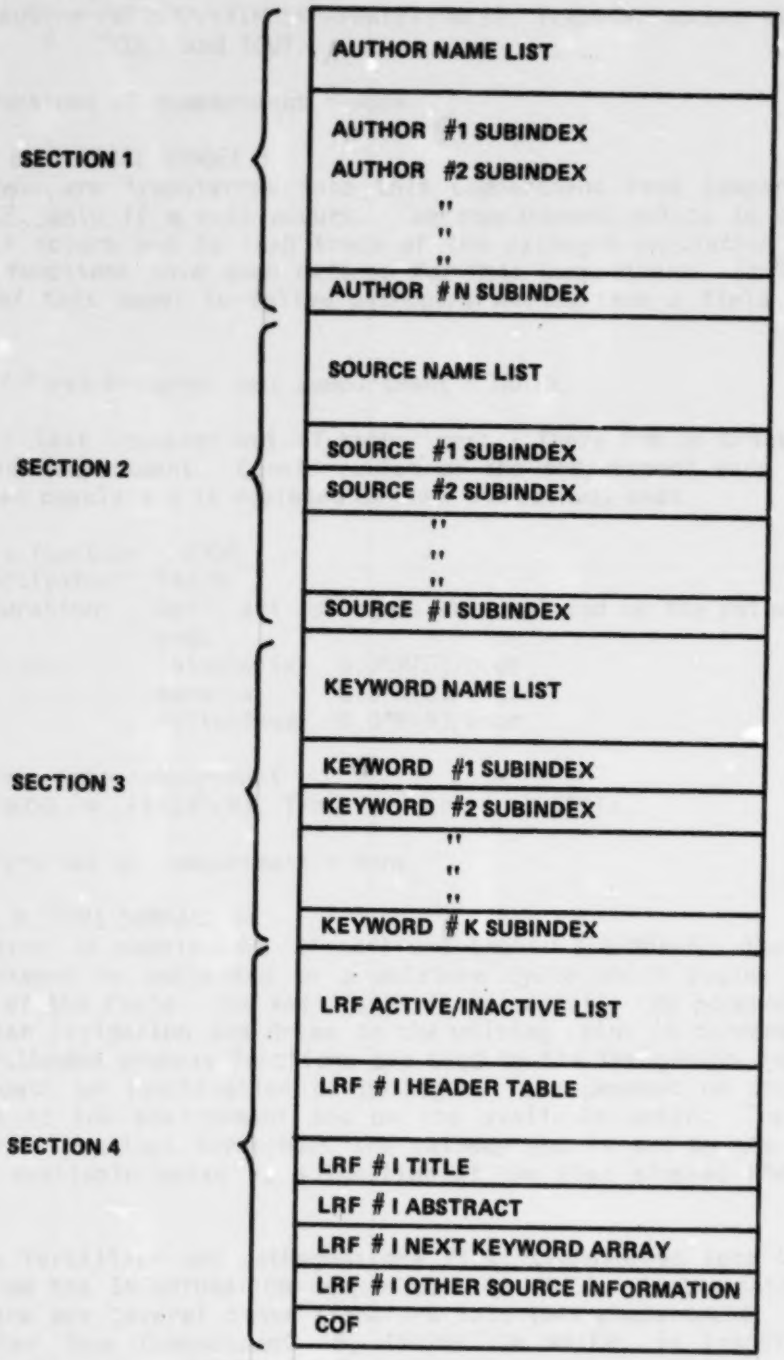
SECTION 1
AUTHOR NAME LIST
AUTHOR #1 SUBINDEX
AUTHOR #2 SUBINDEX
"
"
"
AUTHOR # N SUBINDEX
SECTION 2
SOURCE NAME LIST
SOURCE #1 SUBINDEX
SOURCE #2 SUBINDEX
"
"
"
SOURCE # I SUBINDEX
SECTION 3
KEYWORD NAME LIST
KEYWORD #1 SUBINDEX
KEYWORD #2 SUBINDEX
"
"
"
KEYWORD # K SUBINDEX
SECTION 4
LRF ACTIVE/INACTIVE LIST
LRF # I HEADER TABLE
LRF # I TITLE
LRF # I ABSTRACT
LRF # I NEXT KEYWORD ARRAY
LRF # I OTHER SOURCE INFORMATION
COF

Figure B-6. Sequential file structure of the LBD.

BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8''

PAGE NUMBER
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IN/OUT. The resultant file is in binary format, thus maximizing the available space for LDB storage.

This file is known as local file OLDLRF for reading and NEWLRF for writing. The user has the option of maintaining a backup LDB or several LDB files by assigning NOS unique permanent file names via the SAVE and REPLACE commands discussed in the preceeding subsection. Another option is discussed in the next subsection pertaining to the storage of LDB on a magnetic tape medium.

The LDB sequential file is organized into four distinct sections as illustrated in Figure B-6. Each section contains the information needed to reconstruct a working LDB within the storage program. The first three sections have information for the authors, sources, and keywords used within an LDB. The last section contains all the LRFs within the LDB. Further information on the structure of this file is detailed in Section B-3 under programmer/analyst's guide.

TFILE Backup/Storage Capabilities

The sequential file containing the LDB can exceed the storage capacity of the user's permanent file indirect access disk area when enough records are entered. The lengths of the records determine how many can be entered before this happens. To provide permanent storage for these LDB files, the TFILE magnetic tape system was used. With the FILE and the RECALL parameters, the user can store or retrieve the LDB files for later use. The TFILE system is explained in detail in the NOS NEWS NOTES 15. The tape ID numbers which are currently being used are 10146 and 10147.

EXECUTING THE STORAGE PROGRAM

This section gives the system configuration required to run the storage program. An example run is included to aid the user in executing the storage program.

Hardware Requirements

This release of the storage program requires a Tektronix 4026 terminal and a data phone link to a CDC 6600 computer system. The storage program currently resides on the Sandia Laboratories CDC 6600 computer system. The storage program should work on any computer system with a data phone link compatible with the CDC 6600 computer. The system configuration of the storage program was illustrated in Figure B-2.

Storage Program Cataloged Procedures

To facilitate modification, debug, and execution of the Library Storage Program, several procedure files were created. Figure B-7 lists the Update Procedure file, where the user can make temporary modifications; Figure B-8 illustrates the Librarian's Update Procedure file, by which permanent changes are made; and Figure B-9 shows the Listing Generator to produce hardcopy of the program.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

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```
COMMENT. PROGRAMMER'S UPDATE PROCEDURE FILE.
SETTL,1100.
GET,PTHLOPL/UN=RLWARD.
GET,UPDRT/UN=KDLEY.
RA.
POST,OUTPUT,4. MAKE ANY LAST MINUTE PERMANENT CHANGES TO UPDRT.
XEDIT,UPDRT.
RA.
REPLACE,UPDRT/UN=KDLEY.
POST,OUTPUT,4. READ IN OTHER ID'S AT BOTTOM, OR ADD DEBUG MODS.
XEDIT,UPDRT.
RA.
POST,OUTPUT,4. BEGINNING UPDATE CORRECTIONS.
UPDATE,P=PTHOPL,I=UPDRT,S=TEST1X,L=1.
POST,OUTPUT,4. OPPORTUNITY TO INSPECT CHANGES,BUT NOT MODIFY THEM.
XEDIT,TEST1X.
RETURN,PTHOPL,TEST1X,UPDRT.
POST,OUTPUT,4. UPDATE COMPLETED. BEGINNING FTN COMPILATION.
FTN,I,A,OPT=0,R=0,B=LMODS.
RETURN,COMPILE.
POST,OUTPUT,4. FORTRAN COMPILATION COMPLETED,BEGINNING COPYL OPERATION.
GET,PTHLGO/UN=RLWARD.
COPYL,PTHLGO,LMODS,LGO,,AR.
RETURN,PTHLGO,LMODS.
POST,OUTPUT,4. COPYL OPERATION COMPLETED, BEGINNING LOAD.
RA.
LDSET(MAP=SBEX/PTHMAP)
LGO.
RETURN,ZZZZZ31,STATF.
RA.
Q,F.
SDAYBOT.
COPYEI,PTHMAP,MPLGO.
RA.
XEDIT,MPLGO,I=MAPMOD.
EXIT.
POST,OUTPUT,4. ABNORMAL TERMINATION PROCEDURE.
RETURN,ZZZZZ31,STATF.
RA.
COPYEI,PTHMAP,MPLGO.
XEDIT,MPLGO,I=MAPMOD.
RA.
Q,F.
SDAYBOT.
 END OF INFORMATION ENCOUNTERED.
```

Figure B-7. Storage program update procedure file.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

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```
COMMENT. LIBRARIAN'S UPDATE PROCEDURE FILE.
SETTL,1100.
GET,UPDKH.
POST,OUTPUT,4. READ IN OR ADD ALL PERMANENT UPDATE CORRECTIONS.
XEDIT,UPDKH.
RA.
REPLACE,UPDKH.
GET,PTHOPL.
RA.
COPYSBF,UPDKH,LLUPCORR.
REWIND,UPDKH.
POST,OUTPUT,4. BEGINNING UPDATE CORRECTIONS.
UPDATE,F,N=TBACKUP,P=PTHOPL,I=UPDKH,S=TEST1,O=LLUPCORR,L=A1234,C=0.
PRINT,LLUPCORR.
RETURN,LLUPCORR,PTHOPL.
POST,OUTPUT,4. FIRST UPDATE COMPLETED.
UPDATE,F,P=TBACKUP,N=PTHOPL,C=0,I=NIL,L=A1234,O=LIST.
RETURN,PTHOPL.
RETURN,NIL,TBACKUP,PTHOPL.
POST,OUTPUT,4. PTHOPL REPLACED. BEGINNING Q UPDATE.
GET,PTHOPL.
GET,UPDMSTR.
UPDATE,Q,P=PTHOPL.I=UPDMSTR,L=1.
RETURN,PTHOPL.UPDMSTR.
POST,OUTPUT,4. UPDATE COMPLETED.
GET, PTHLGO.
POST,OUTPUT,4. BEGINNING FTN COMPILATION.
FTN,I,A,OPT=2,R=0,B=PTHLGO,L=LIST.
RA.
PRINT,LIST.
RETURN,COMPILE,LIST.
REPLACE,PTHLGO.
POST,OUTPUT,4. PTHLGO REPLACED. BEGINNING LOAD.
GET,PTHMAP.
RA.
LDSET(MAP=SBEX/PTHMAP)
PTHLGO.
RETURN,ZZZZZ31,PTHLGO,XWAIT.
RA.
SDAYBOT.
Q,F.
COPYCF,PTHMAP,MPLGO.
RA.
XEDIT,MPLGO,I=MAPMOD.
EXIT.
POST,OUTPUT,4. ABNORMAL TERMINATION OF PROCEDURE - CALL PROGRAMMER.
RETURN,ZZZZZ31,PTHLGO,XWAIT.
COPYCF,PTHMAP,MPLGO.
RA.
SDAYBOT.
Q,F.
 END OF INFORMATION ENCOUNTERED.
```

Figure B-8. Storage program librarian's update procedure.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

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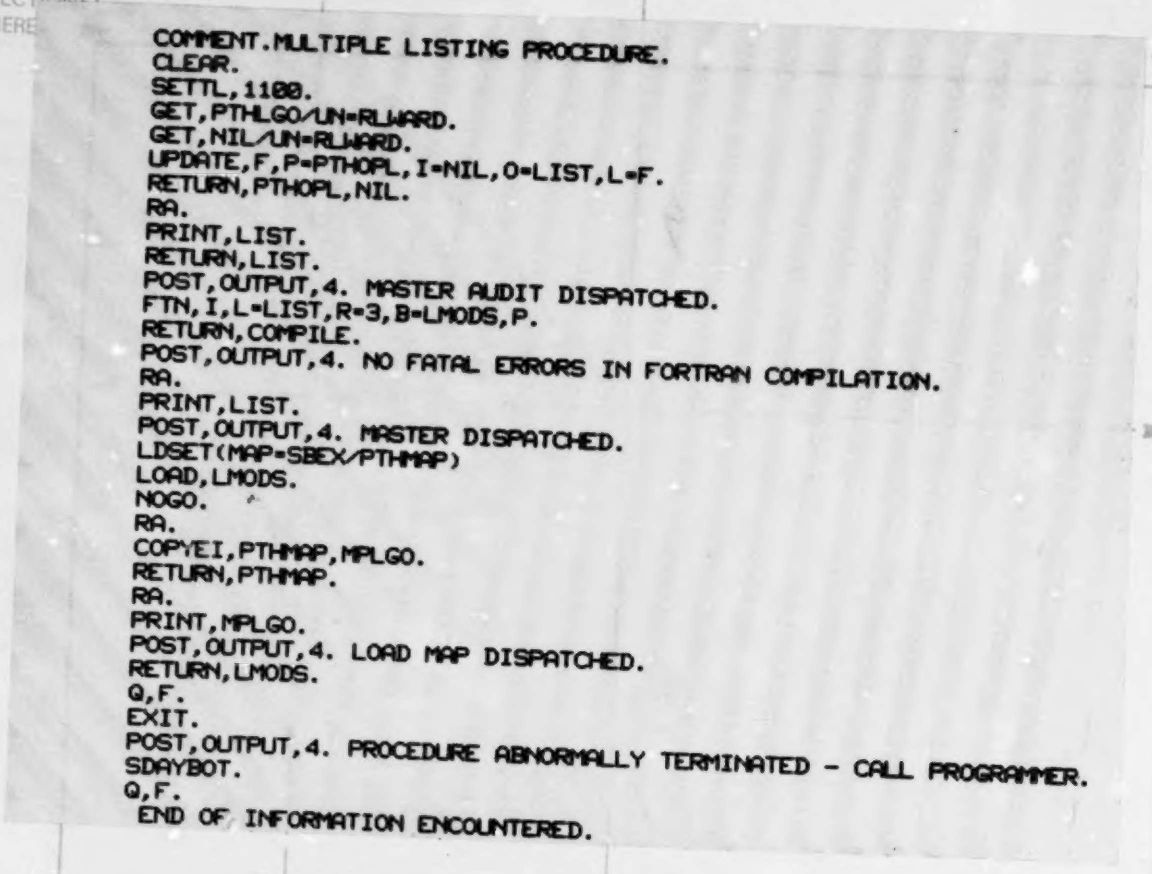

```
COMMENT.MULTIPLE LISTING PROCEDURE.
CLEAR.
SETTL,1100.
GET,PTHLGO/UN=RLWARD.
GET,NIL/UN=RLWARD.
UPDATE,F,P=PTHOPL,I=NIL,O=LIST,L=F.
RETURN,PTHOPL,NIL.
RA.
PRINT,LIST.
RETURN,LIST.
POST,OUTPUT,4. MASTER AUDIT DISPATCHED.
FTN,I,L=LIST,R=3,B=LMODS,P.
RETURN,COMPILE.
POST,OUTPUT,4. NO FATAL ERRORS IN FORTRAN COMPILATION.
RA.
PRINT,LIST.
POST,OUTPUT,4. MASTER DISPATCHED.
LDSET(MAP=SBEX/PTHMAP)
LOAD,LMODS.
NOGO.
RA.
COPYEI,PTHMAP,MPLGO.
RETURN,PTHMAP.
RA.
PRINT,MPLGO.
POST,OUTPUT,4. LOAD MAP DISPATCHED.
RETURN,LMODS.
Q,F.
EXIT.
POST,OUTPUT,4. PROCEDURE ABNORMALLY TERMINATED - CALL PROGRAMMER.
SDAYBOT.
Q,F.
 END OF INFORMATION ENCOUNTERED.
```

Figure B-9. Storage program listing generator.

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BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

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The following list identifies files and their function for the Library Storage Program Update Procedure file.

File Name	Purpose
PTHOPL	Storage program old program library.
UPDRT	Update correction directives.
TEXT1X	Temporary source of updated program.
PTHLGO	LGO of old storage program.
LMODS	Compiled modifications for old LGO.
PTHMAP	Map of storage program.
MAPMOD	XEDIT Input commands to search MAP for errors.
MPLGO	LGO version of MAP.

Responses to Commands

The following is a list of the commands and/or questions which are part of the Library Storage Program. The commands are presented in the order in which they would normally appear during an abstract entering session. Each command is reproduced as it would appear on the screen of a Tektronix 4025 interactive terminal and is followed by an explanation of the proper responses.

COMMAND

```
**WARNING-MASTER DATA BASE FILE (OLDLRF) EMPTY**
          NEW DATA BASE WILL BE CREATED
     DO YOU WISH TO CONTINUE?  (1=YES; 0=NO)
```

RESPONSE This is the first command or question encountered in the Library Storage Program. If the abstracts to be entered during the session are to be added to an existing data base file and if that file had been called prior to execution of the program, this message would not appear. Instead, the program would start with the first section of the LRF form.

If the creation of a new data base file is expedient, type "1" and hit the return key. A local file will be created which will hold the abstracts being entered during the session. This file is named during a SAVE procedure at the end of the session.

If the abstracts to be entered should be added to an existing file, type "0" and hit the return key. A message will be returned indicating how much computer time was used in execution of the Library Storage Program. This will be followed by the prompt character, "/". In order to continue, get the file to which the abstracts should be entered. Recall the Library Storage Program and execute the program.

COMMAND

```
TYPE IN INFORMATION.  TAB MOVES CURSOR TO THE NEXT FIELD.  WHEN
DONE TYPE SEND KEY (F8).
```

9-1/8"
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

RESPONSE This is the command which appears at the top of the first section of the LRF form. Wait for the entire section of the LRF form to appear on the screen before proceeding. A bell will sound when the form is complete. Hit the return key to position the cursor in the first space of the AUTHOR field. Type in the name of the principal author of the article being abstracted. The surname should be typed first followed by a space and the initial letter of his given name. The AUTHOR field is used in the Library Retrieval Program. Because of the very literal way in which abstract fields are searched during retrieval operations, care must be taken to enter the author name in accordance with the rules.

These rules preclude the use of any punctuation in the AUTHOR field. Multiword names such as "de la O" or "Van der Noote" must be entered without spaces, becoming DELAO and VANDERNOOTE. The apostrophe in names such as "L'Estrange" or "O'Brien" is deleted and the names are entered as LESTRANGE and OBRIEN. Hyphens and any other punctuation marks are deleted. "Leith-Ross" would be entered as LEITHROSS. A space must follow the surname. This is used as a signal in the Library Retrieval Program. Only one initial may follow the surname. Periods, commas, etc, should not be typed in this field. The storage program will accept any character but the retrieval program cannot process punctuation marks in searched fields. There is a 20-character limit to the length of an entry to the AUTHOR field. Longer names are truncated. The surname should be truncated at the 18th letter and a space should separate the shortened surname and the initial of the given name. Thus, if an article was authored by J. Alice O'Brien-Mies Van der Rohre, OBRIENMIESVANDERRO J would be the entry in the AUTHOR field.

After entering the name of the primary author, hit the tab key to position the cursor in the first space of the OTHER AUTHOR field. The names of up to five secondary authors may be typed in this field. Names in this field may include normal punctuation because the field is not used during retrieval operations. The use of an apostrophe is not recommended. Not all computer systems process this character in the same way. For the sake of consistency, names should be entered surname first followed by a space and the initial of the given name. A comma may be used to separate individual entries. It is important to type to the end of each line included in the field and it is not necessary to return at the end of a line. The cursor will move automatically to the next lower line in the field. If a name ends in the last space of a line, be sure to put a separating comma or space in the first position of the next line. The field has a length limit of 5 names of 20 characters each including spacing and punctuation or a total length of 100 characters. If an article is credited to more than six authors, use the term "et al." in place of the sixth (fifth secondary) author. This will indicate to the reader that the citation is incomplete.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

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Use the TAB key to position the cursor in the first space of the TITLE field. This field is used in the retrieval program and therefore may not contain any punctuation. The title should be typed to the end of each line in the field. Allow the cursor to automatically begin the next line. Spacing in the TITLE field is as important as it is in the AUTHOR field. If a word ends at the end of a line, be sure to include a space in the first position of the next line. A double space is a signal to the retrieval program that the end of a title has been reached. Do not double space in the middle of a title. Numbers may be used in titles. There is a 200-character limit to the field. Longer titles are simply truncated. Do not abbreviate in a title.

After completely typing the title use the TAB key to move the cursor to the first space of the SOURCE field. In this field, type either the terms BOOK or PROCEEDINGS, if appropriate, or type in the standard abbreviation for the name of the periodical in which the abstract article was published.

Detailed instructions for abbreviation of journal names are given elsewhere (page B-4). In brief, each word in the title is abbreviated and entered without punctuation; spaces separate each abbreviated part of the name; unnecessary words such as articles, prepositions, and conjunctions are eliminated; and the title is truncated on the 20th character to meet the length limitations of the field. This field is used by the retrieval program.

The TAB key is used once again to move the cursor into the OTHER SOURCE INFO field. This field is designed to contain any information necessary to further identify the source of an article and necessary to facilitate acquisition of the article itself. Punctuation is allowed. Because the field has a 200-character limit, abbreviation of terms is suggested. It is convenient to give journal citations in the standard form, volume number:page-page (year). Information concerning books and proceedings might include: the full title of the publication, name of author or editor, publisher's name and address, and the year of publication. Number codes identifying Government publications and reference to other works in a series belong in this field.

Once the entire first section of the LRF form is complete, the TAB and BACK TAB keys may be used to move the cursor to any field to correct or change any part of the entry. When satisfied with the entire form hit the SEND key (F8). This section of the LRF is sent from the interactive terminal to the data base file field by field, a process that takes several moments. Do not hit the SEND key twice.

COMMAND	DO YOU WISH TO RE-ENTER THIS SECTION (1=YES; 0=NO).
RESPONSE	This command will appear after the first section of the LRF form has been placed in a local file. Wait for the prompt character,

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

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"?", before proceeding. If there were mistakes in entry of the first section of the LRF form, type "1" and return. The first section of the LRF form will be returned to the screen and the entry just sent will be erased. Reenter this section remembering the instructions given above.

If the section sent was acceptable, type "0" and return. This places the entry in the data base file and returns the second section of the LRF form.

COMMAND CHECK THE PROPER BLANKS. TERMINATE WITH THE SEND KEY (F8).

RESPONSE This is the command at the top of the second section of the LRF form. This section will be referred to as the keyword section. Wait for the entire section to appear on the screen before proceeding. A bell will sound when the form is complete. Hit the RETURN key to position the cursor in the first keyword blank. If this keyword, REVIEW, describes the article being abstracted, hit "X"; if not, hit the TAB key to leave it blank and move to the second keyword, SURVIVAL. Any character may be used to check a keyword but consistent use of one character such as "X" will eliminate unnecessary decisions. The TAB key will move the cursor from word to word and each time a keyword is checked, the cursor will automatically move to the next. The BACK TAB key can be used to return to any keyword.

As in the first section of the LRF form, the keyword section is sent as a unit by hitting the SEND key (F8). Therefore, changes can be made until the SEND command is given.

COMMAND DO YOU WISH TO RE-ENTER THIS SECTION (1=YES; 0=NO).

RESPONSE This command will appear after the abstract section is sent in the same way as after the first two sections of the LRF form. If the abstract section has been entered properly, hit "0" and return. The program will proceed to the next command. If the abstract should be retyped, hit "1" and return. A blank abstract section will appear on the screen and the incorrect abstract will be erased.

COMMAND DO YOU WISH TO ENTER ANOTHER NEW LRF (1=YES; 0=NO).

RESPONSE This command is the last in the storage program. All three sections of an abstract have been entered and held in a local file. If a second abstract is to be entered, type "1" and return. The first section of the LRF form will be returned to the screen ready to accept the next set of source information. If it is prudent to save the entered LRF by placing it immediately in a permanent file or if another LRF is not going to be entered in this session, type "0" and return.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

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There will be a wait followed by the return of a computer usage message after a "0" is sent. Finally, the prompt character, "/" will be returned indicating that the Library Storage Program is no longer active. At this time the abstracts entered during the session should be moved to a permanent data base file by either a SAVE command if a new file was created or a REPLACE command if the abstracts are being added to an existing file.

Example Run

Step 1 - Log Into Computer System--

The Library Storage Program is designed to be run on a Tektronix 4025 interactive terminal. The user phones the computer and, after hearing the carrier tone, switches to "data" transmission and replaces the handset. The RETURN key is hit twice and the computer will respond with a system message. If the system is "up," hit a return again. Type in the password and user number assigned and return. The computer will return a terminal number. Record this number. It is necessary for recovery procedures. The computer will proceed to send a system query. Respond by typing "HALF" and then hit return. Each of these letters will be repeated twice but all commands hereafter will be correct. If the letters in the password and system response are lower case, press the TTY LOCK key. The computer will respond to your system response with "READY". Now type "BATCH" and return. The computer will respond with a code "$RFL,0." followed by a prompt character, "/", with a cursor next to the prompt.

Example:

```
6000 SYSTEM UP
79/07/02  10,28,40
SANDIA NOS SN53 E65           NOS 1.2 - 460
USER NUMBER, PASSWORD
KEHAIN, TOGO
TERMINAL:         110, TTY
RECOVER/SYSTEM:  HHAALLFF
READY.
BATCH
$RFL,0.
/_
```

Step 2 - Call Library Storage Program--

At this point, the decision is made whether to start a new file or add to an old one. Both options are shown in examples below. To start a new file, simply get the Library Storage Program and then load it. To add abstracts to an existing file, get that file before getting the Library Storage Program and then load the program. In either case, one types the commands as given in the examples, hitting the RETURN key after each line. It is necessary to wait for the prompt character "/" before starting each new line of typing.

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Example - Start new file

```
/GET, PTHLGO
/RA
/PTHLGO
```

Example - Add to old file

```
/GET, OLDFILE = LRFEPA (where LRFEPA is the name of file you are
                adding to)
/GET, PTHLGO
/RA
/PTHLGO
```

There will be a wait while the program is loaded. If a new file is being created, a warning will be printed out:

```
** WARNING - MASTER DATA BASE FILE (OLDLRF) EMPTY **
            NEW DATA BASE WILL BE CREATED
DO YOU WISH TO CONTINUE?  (1=YES; 0=NO)
?
```

The "?" prompt character indicates that the Library Storage Program is active. Respond by typing "1" and return if you wish to continue. When adding to an old file, the first indication that the program is active is the appearance of the first section of the LRP form.

Step 3 - Enter LRFs--

Wait for the entire section of the LRF form to appear on the screen. A bell will sound when it is complete. The cursor will lie below the shaded form area. Compare the form with the example in the user's guide (Figure B-4). If it is altered, check the instructions in the error message section of the user's guide. If it appears proper, hit the RETURN key to bring the cursor into the first field. Type in the identifying information for the article being abstracted. Detailed instructions for entering LRF information are given in the Response to Commands (page B-21). Be particularly careful not to use punctuation marks in the AUTHOR, TITLE, and SOURCE fields and to observe the length limits of each field. Corrections are made by hitting the CONTROL and "H" keys together to move backward. Use the TAB and BACK TAB keys to move from field to field. The RETURN key will move the cursor to the next field but the tab option is safer. When the form is filled, check it for accuracy and format before hitting the SEND key (F8).

It takes several moments for the first section of the LRF to be sent to the computer. Wait patiently. When the whole section has been received the program will return with a reentry query:

```
DO YOU WISH TO RE-ENTER THIS SECTION (1=YES; 0=NO)
?
```

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Type the appropriate response next to the prompt character and return. An affirmative response, "1", will void the information just entered on the first section of the LRF form and return this section so that you may try again. A negative response, "0", will signal for the second section of the LRF form.

Wait for the entire keyword section to appear on the screen. A bell will ring when it is ready. Check the format against the example given in the user's guide (Figure B-5). Hit the RETURN key to position the cursor in the first keyword blank. Type an "X" to mark the blank or hit the TAB key to skip it. The BACK TAB key can be used to correct mistakes. When the appropriate keywords have been marked, send this section of the LRF form by hitting the SEND key (F8).

The program will return with the reentry query:

```
DO YOU WISH TO RE-ENTER THIS SECTION (1=YES; 0=NO)
?
```

An affirmative response will return the keyword section but will not affect the first section of the LRF form. Each section of the form is treated as a separate unit and may be reentered as many times as are necessary. A negative response will move the program forward to the third and last section of the LRF form.

The last section of the LRF form, on which the abstract itself is typed, differs from the first two sections. Each line in the abstract section is sent separately to the computer when the RETURN key is hit. Type each line of the abstract carefully, pausing at the end to make any corrections by backspacing. Do not use the TAB key while entering this section. When a line has been satisfactorily entered, return. The cursor will move to the next line. Do not send blank lines in the abstract section. This will result in a fatal error. As with the other two sections, if mistakes are made it is possible to send the abstract section but void it by typing a "1" or yes in answer to the reentry query.

The length of each line in the abstract section must not exceed 70 characters. Beyond this limit, characters are not recorded in the computer file and are lost. If characters are typed to the far edge of the screen, the internal program of the Tektronix terminal will return the cursor to the next line. It is impossible to go back to the line overtyped and it is difficult to decide which characters are lost. The line of "+'s" at the top of the abstract section is a guide to line length. The completion command for the abstract section is a "$". (This symbol does not "send" the section, as each line was received when the return was hit.) Avoid using the symbol within the abstract itself. Other advice on the use of symbols within the abstract is found in the Response to Commands section of the manual.

After the last line of the abstract section has been sent and the "$" received by the computer, the familiar reentry query will be returned. Respond to this question as for the other two sections. If the abstract

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has been satisfactorily entered and a negative response given, the program will proceed to another query:

```
          YOU WISH TO RE-ENTER THIS SECTION (1=YES; 0=NO)
          ? 0
          DO YOU WISH TO ENTER ANOTHER NEW LRF (1=YES; 0=NO)
          ?
```

An affirmative answer to this query will return a fresh first section of the LRF form ready for the next abstract. A negative answer will exit from the Library Storage Program. There will be a wait but the computer will eventually return with a usage message followed by a prompt character, "/" on the next line. This character indicates that the Library Storage Program is no longer active.

Example:

```
     2.038 CP SECONDS EXECUTION TIME
     /_
```

Step 4 - SAVE Entered Abstracts--

The information entered on the LRF forms during any session with the terminal is in a temporary file until it is moved to the user's permanent file by either a SAVE or REPLACE command. The SAVE command is used when a new file has been created. The REPLACE command is used when the abstracts entered during the session are being added to an existing file. The decision on the type of file was made in Step 2. The command used now must agree with that decision. Below is an example of each operation.

Example - Save new file

```
     /RA
     /SAVE, NEWLRF = NFILE (where NFILE is the name of file created)
```

Example - Save entered abstracts in existing file

```
     /RA
     /REPLACE, NEWLRF = LRFEPA (where LRPEPA is the name of the file
                                 obtained in step 2)
```

Step 5 - Log Off Computer--

After saving the entered abstracts, the user may recall the Library Storage Program and enter more information or log off the computer. An example of a log off procedure is given.

Example:

```
     /BYE
     11.16.44        79/07/02
     OFF KEHAIN
     TTY 100         5.236 SRU
```

<u>Problems/Error Messages</u>

Listed below are some of the more common errors encountered in using the Library Storage Program. The most obvious problems with the system are

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caused by noise in the lines between the interactive terminal and the computer. These problems are reduced by entering abstracts during nonpeak computer and telephone operation periods. The type of error message that will be returned when a noisy signal is sent is not always predictable. The remedies given here to the more commonly returned error messages can be applied to similar messages. The error messages quoted below have been shortened. Only the first line is usually given. This is enough information to identify the problem. The remainder of the message is important only for programmers.

ERROR 1.	Hit SEND key (F8) a second time before all of the first section of an LRF form had been sent to the computer.
ERROR MESSAGE	The "DO YOU WISH TO RE-ENTER THIS SECTION (1=YES; 0=NO)" command will appear on the screen as usual but after either answer is sent, several "* RE-ENTER LAST LINE" statements will appear followed by an "< ERROR, RETYPE RECORD AT THIS FIELD" and a prompt character, "?".
REMEDY	Type a "1" after the prompt character and hit the RETURN key. The first section of the LRF form will appear. Reenter the information in this section, send, and be patient while all lines of the form are sent. The lights marked TXD and RXD on the modem will blink alternately eight times while the first LRF section is sent. As long as they are blinking everything is all right.
ERROR 2.	Noise interferes with sending of the first section of the LRF form.
ERROR MESSAGE	Instead of returning the "DO YOU WISH TO RE-ENTER THIS SECTION (1=YES; 0=NO)" query, a "* RE-ENTER LAST LINE" statement will be returned, once or several times.
REMEDY	Hit the RESET key (F1). A coded status report will appear on the screen. Ignore this and when the prompt character appears type a line of random letters and return. Continue feeding short lines of characters when prompted until a "DO YOU WISH TO RE-ENTER THIS SECTION (1=YES; 0=NO)" command is returned. Now, type "1", hit return and when the first section of the LRF form appears, reenter abstract information.
ERROR 3.	Typing a character other than "1" or "0" in response to the "DO YOU WISH TO RE-ENTER THIS SECTION (1=YES; 0=NO)", "DO YOU WISH TO CONTINUE? (1=YES; 0=NO)", or "DO YOU WISH TO ENTER ANOTHER NEW LRF (1=YES; 0=NO)" commands.
ERROR MESSAGE	"____ < ERROR, RETYPE RECORD AT THIS FIELD", followed by a prompt character, "?". The character mistyped will be in the space indicated with a "__" here.

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REMEDY Type the appropriate character, "1" for yes or "0" for no, next to the prompt and return. The program will respond normally to the entered character and either return the last section of the LRF or go on to the next.

ERROR 4. Send any section of the LRF form completely blank.

ERROR MESSAGE "FATAL ERROR 58 - AREA SPECIFICATION BAD - FWA GT. LWA" followed by the prompt character "/".

REMEDY Any time the prompt character "/" is returned, the Library Storage Program is no longer active. All abstracts entered but not saved before a fatal error can be lost. It is advisable to try a SAVE or REPLACE operation immediately. If the command is taken, get the Library Retrieval Program and query the last two or three abstracts entered to see if any were lost. Then, recall the storage program in order to begin entering abstracts again.

The system will not always accept a command after a fatal error. If the SAVE or REPLACE operation is unsuccessful, try a recovery procedure. Break the line. Clear the interactive terminal. Then, log into the computer again following normal procedures. Respond to the "RECOVER/SYSTEM" query by typing "RECOVER, #", where "#" is the number of the terminal you were logged into before breaking the line. The computer will respond with:

```
RECOVERY COMPLETE.
     LAST COMMAND = XXX
     NEXT OPERATION = XXX
ENTER * CR * TO CONTINUE:
```

Hit the RETURN key. A prompt character "/" will be returned. Attempt a SAVE or REPLACE operation. The "X's" in the computer response above will differ depending on where in the program the fatal error occurred. Recovery can be attempted only once and within 15 minutes of a break in the line. If the terminal number is incorrectly given, the chance of recovery is lost. If the recovery procedure is not successful, you must start completely over again by calling the Library Storage Program. All abstracts not saved are lost and must be reentered.

ERROR 5. Send blank line in the abstract section.

ERROR MESSAGE "FATAL ERROR 65, END-OF-FILE ENCOUNTERED" followed by a prompt character "/".

REMEDY The Library Storage Program is no longer active. This is indicated by the prompt character "/". Proceed with the instructions given above for ERROR 4. These instructions are the remedy to any fatal error or any occurrence which returns a "/" prompt character.

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ERROR 6. Noise on the line can be interpreted as a fatal error by the computer.

ERROR MESSAGE Any "FATAL ERROR ___" may be returned.

REMEDY Proceed with instructions given in ERROR 4, listed above.

ERROR 7. Noise on the line interferes with the structure of a section of the LRF form. The form which appears on the screen may contain holes in the shading, nonsense characters, be missing one or more lines, etc.

ERROR MESSAGE None. It is important to be familiar with the format in order to know when an altered form appears. See Figures 4 and 5.

REMEDY Fill in one or two fields with random letters. Send the section. When the "DO YOU WISH TO RE-ENTER THIS SECTION (1=YES; 0=NO)" query is returned, type "1" and return. The section of the LRF form will be returned, hopefully in better condition.

6-1/2"

ERROR 8. Attempting a SAVE or REPLACE operation when there is insufficient file space available.

ERROR MESSAGE "CATALOG OVERFLOW"

9-1/8"

REMEDY The abstracts entered during the session are in a temporary file, and will remain there while space is found in the permanent file area as long as the line is not broken. The recovery procedure should work if it is. Space is created in the permanent file area by removing unnecessary files. The normal procedure would be to do a CATLIST and determine which files are expendable. Files may be moved to tape. Expendable or moved files are then purged and the SAVE or REPLACE command repeated. Remember that the PURGE command completely destroys a file. Catalog overflows might best be handled by an experienced programmer who is familiar with the content of all files in the system.

ERROR 9. Limits of LRF files reached.

ERROR MESSAGE There are several possible error messages which are more fully described in the section on the LDB Driver. The general format is "**WARNING - LRF FILE IS FULL, THIS LRF CANNOT BE ADDED." This is followed by the title of the LRF which cannot be added and a message, "GET A PROGRAMMER TO EXTEND NAMED COMMON/LRFNDX/."

REMEDY There are limits to the number of abstracts which can be placed in a file and there are also limits to the number of different authors and sources which can be specified. If error messages indicating that these limits have been reached are returned, the user should contact an experienced programmer to extend the program limits.

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SECTION B-3

LIBRARY STORAGE PROGRAMMER/ANALYST GUIDE

This guide is intended to aid an individual knowledgeable in the use of the Library Storage Program (LSP) and competent as a FORTRAN programmer on the CDC 6600 computer. This guide, when used in conjunction with the appendix, provides the programmer/analyst with a comprehensive insight into the program structure, subsystem interaction, and computational procedures that comprise the Library Storage Program. These aids allow the Library Storage Program to be supported, modified, or extended.

PROGRAM OVERVIEW

The main objective of the Library Storage Program is to collect information from LRFs and place it on a computerized central file for later retrieval via the Library Retrieval Program (Sections 4 and 5). The storage program has the capability to add LRF data to an existing central file or to create a new central file. The storage program uses several logical files for building the centralized file. These logical files and their associated logical file names are presented in Table B-3 along with a description of their use. Note that the resultant centralized file is built on logical file TAPE90, logical file name NEWLRF.

The storage program requires 50K octal words of memory to compile and run on the Sandia Laboratories CDC 6600 under FORTRAN IV. The CDC MSIO (mass storage input/output) routines are used extensively for maintaining the internal data base. These routines were used to save memory during program execution and to allow faster update access than is available on a sequential file system.

PROGRAM STRUCTURE

The centralized file is known internally to the storage program as the LDB (library data base) and is maintained as a master index/subindex file using the CDC MSIO routines. For the LDB and the subsequent centralized file to be built internally, several processes occur. These processes are controlled by subprogram drivers which are themselves controlled by the main driver. The upper level driver hierarchy is illustrated in Figure B-10. The LSP driver initializes the processing and is the main interface with the host computer system.

Old File Driver

The old file driver is controlled through subroutine OLDLRF. The main function of this driver is to load the LDB with a previously created

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TYPING GUIDE SHEET
BEGIN FIRST LINE TEXT HERE
DROPPED HEAD; BEGIN SECTION HERE

359
Job G

New Typ

TABLE B-3. LIBRARY STORAGE PROGRAM LOGICAL FILES

Logical File	Logical File Name	Description
TAPE 5	INPUT	User input file
TAPE 6	OUTPUT	User output file
TAPE 89	OLDLRF	Centralized file of an existing library data base
TAPE 90	NEWLRF	Created/Modified centralized file
TAPE 91	———	Maintains the LRF author, source, and keyword inventory
TAPE 92	———	Internal representation of the central file

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FOR TABLES AND ILLUSTRATIONS

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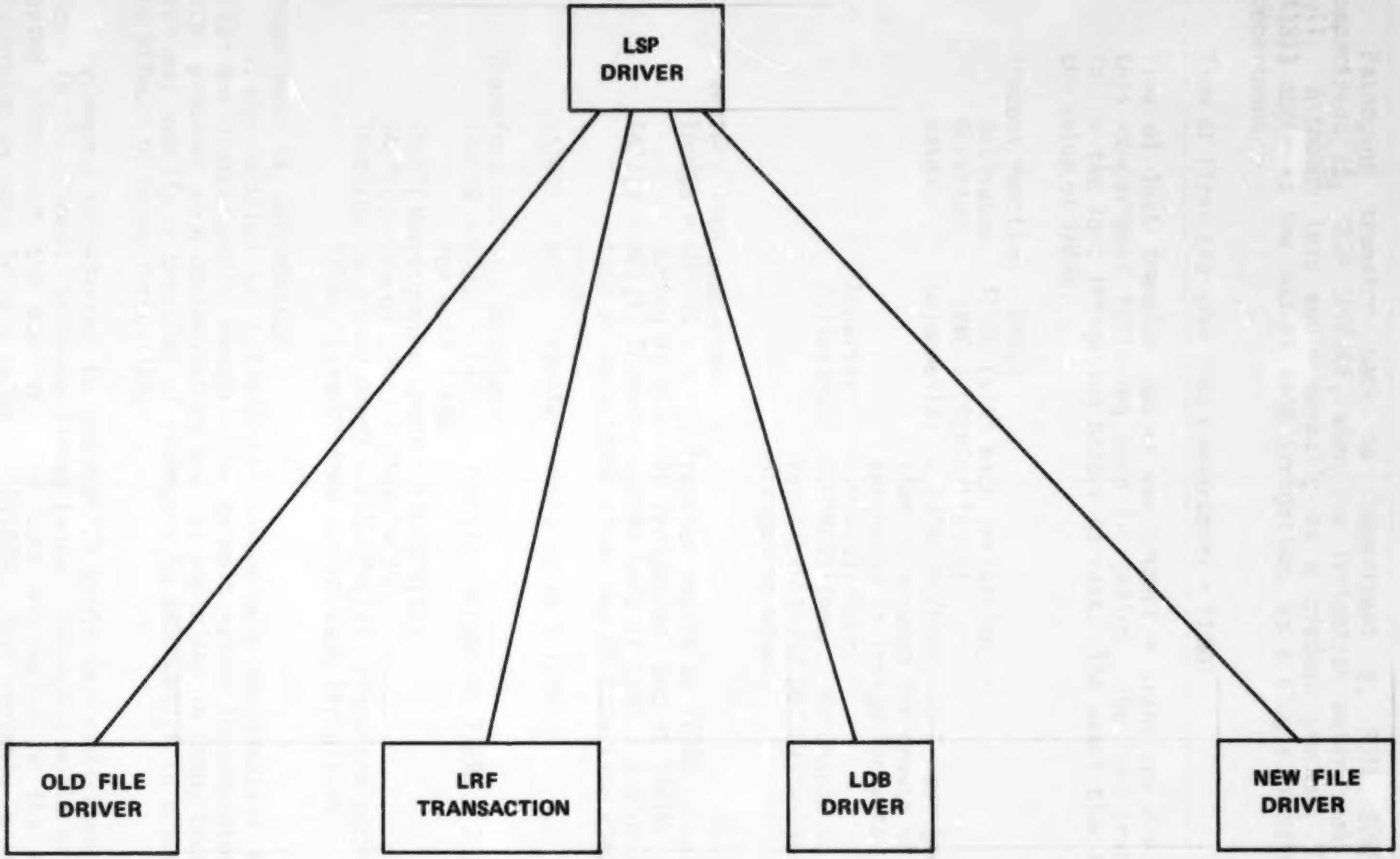
LSP DRIVER
OLD FILE DRIVER
LRF TRANSACTION
LDB DRIVER
NEW FILE DRIVER

Figure B-10. Library storage program upper level hierarchy.

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centralized file. This file must have been created from the Library Storage Program. If a centralized file does not exist (i.e., an end-of-file was detected on logical file name OLDLRD) then the following message is displayed:

```
**WARNING-MASTER DATA BASE FILE (OLDLRD) EMPTY**
          NEW DATA BASE WILL BE CREATED
DO YOU WISH TO CONTINUE? (1=YES; 0=NO)
```

The above message is displayed in case the user neglected to "get" the OLDLRF file. If a new data base is to be created then the user should respond with a "yes" answer. A "no" answer terminates the storage program.

The structure of the old file driver, by subroutine name, is shown in Figure B-11. The subroutines SEQAUT, SEQSRC, SEQKEY, SEQLRF do not call any other storage program routines; however, they do use the CDC routines for I/O purposes. The routines used are documented in the appendix.

Library Data Base Structure

The LDB created using the old file driver is maintained on two files using the CDC MSIO routines. These routines allow LRF information to be created, accessed, or modified without regard for its physical positioning within the LDB. These two files are structured as master index/subindex files. That is, the master index contains address pointers to a random access device which contains another array of address pointers to LRF data contained on the random access device. Thus, it is not necessary to hold an entire LDB in memory, allowing for a substantial overhead savings. These indices are maintained in named commons /QRYNOX/ and /LRFNOX/ and are described in the appendix.

The first file (Query File) is structured by author, source, and keyword as illustrated in Figure B-12. Each of these subindices contains a pointer to an array containing all the authors, sources, and keywords currently residing in the LDB. When a new entry is made to the data base, the first available entry in the array list is located and updated to contain this new entry. Additionally, the position of each entry within these arrays corresponds to the record number in the subindex that contains the pointer to a header array containing the information about that particular author, source, or keyword, For example, suppose a user requests information about AUTHOR 4. Since AUTHOR 4 is contained as the fourth entry in the author name table, the fourth record in the author directory contains a pointer to the header array which corresponds to AUTHOR 4. As shown in Figure 12, the source and keyword directories are structured in the same fashion. The header array contains information that will allow the user to access the LRF file (file #2). The information contained in the header will be the record in the LRF file of the first and last occurrences for the author, source, or keyword, and the number of occurrences for the author, sources, or keyword of interest.

The LRF file is structured in a manner similar to the Query File. But, as illustrated in Figure B-13, the LRF file is much larger than the

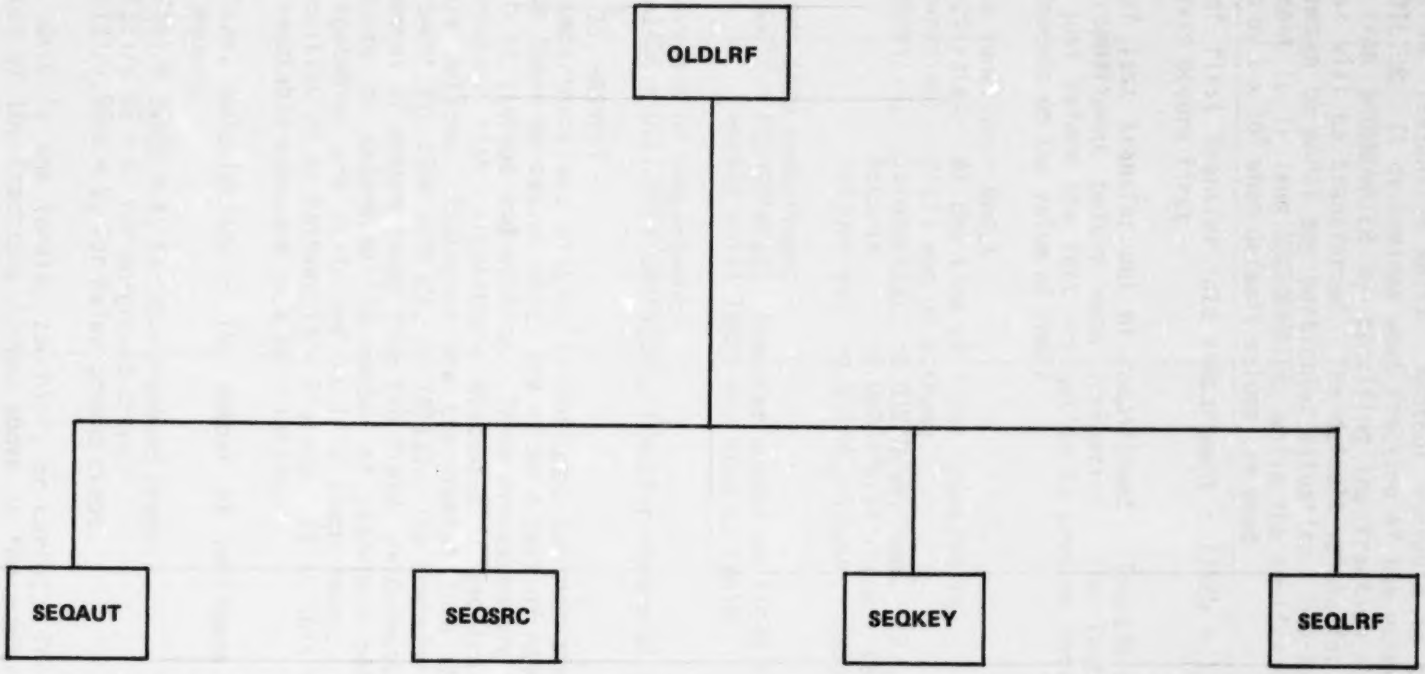
OLDLRF
SEQAUT
SEQSRC
SEQKEY
SEQLRF

Figure B-11. Old file driver subroutine structure.

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BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE

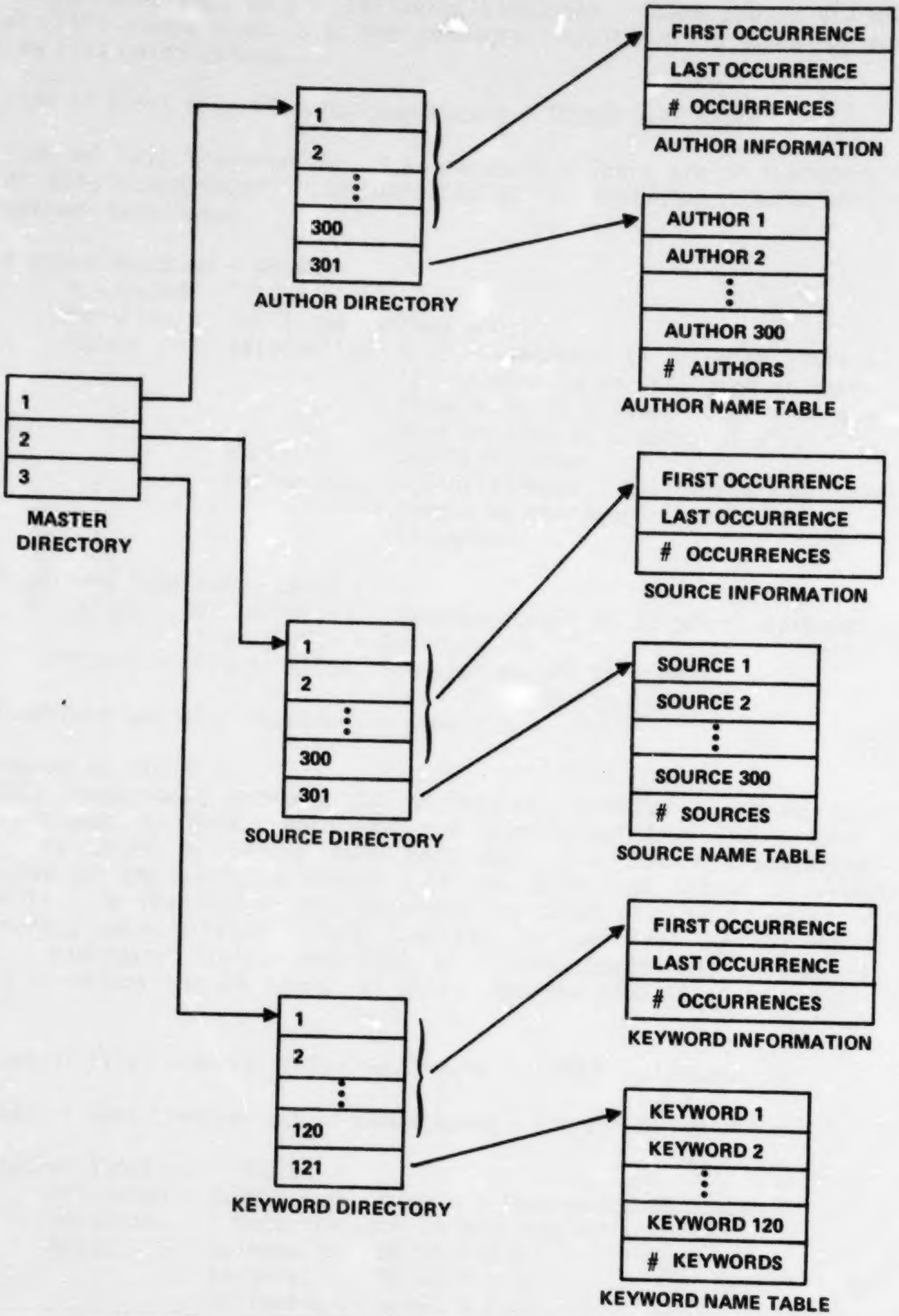
FIRST OCCURRENCE
LAST OCCURRENCE
# OCCURRENCES
AUTHOR INFORMATION
1
2
300
301
AUTHOR DIRECTORY
AUTHOR 1
AUTHOR 2
AUTHOR 300
# AUTHORS
AUTHOR NAME TABLE
1
2
3
MASTER DIRECTORY
FIRST OCCURRENCE
LAST OCCURRENCE
# OCCURRENCES
SOURCE INFORMATION
1
2
300
301
SOURCE DIRECTORY
SOURCE 1
SOURCE 2
SOURCE 300
# SOURCES
SOURCE NAME TABLE
FIRST OCCURRENCE
LAST OCCURRENCE
# OCCURRENCES
KEYWORD INFORMATION
1
2
120
121
KEYWORD DIRECTORY
KEYWORD 1
KEYWORD 2
KEYWORD 120
# KEYWORDS
KEYWORD NAME TABLE

Figure B-12. Library data base structure - Query File.

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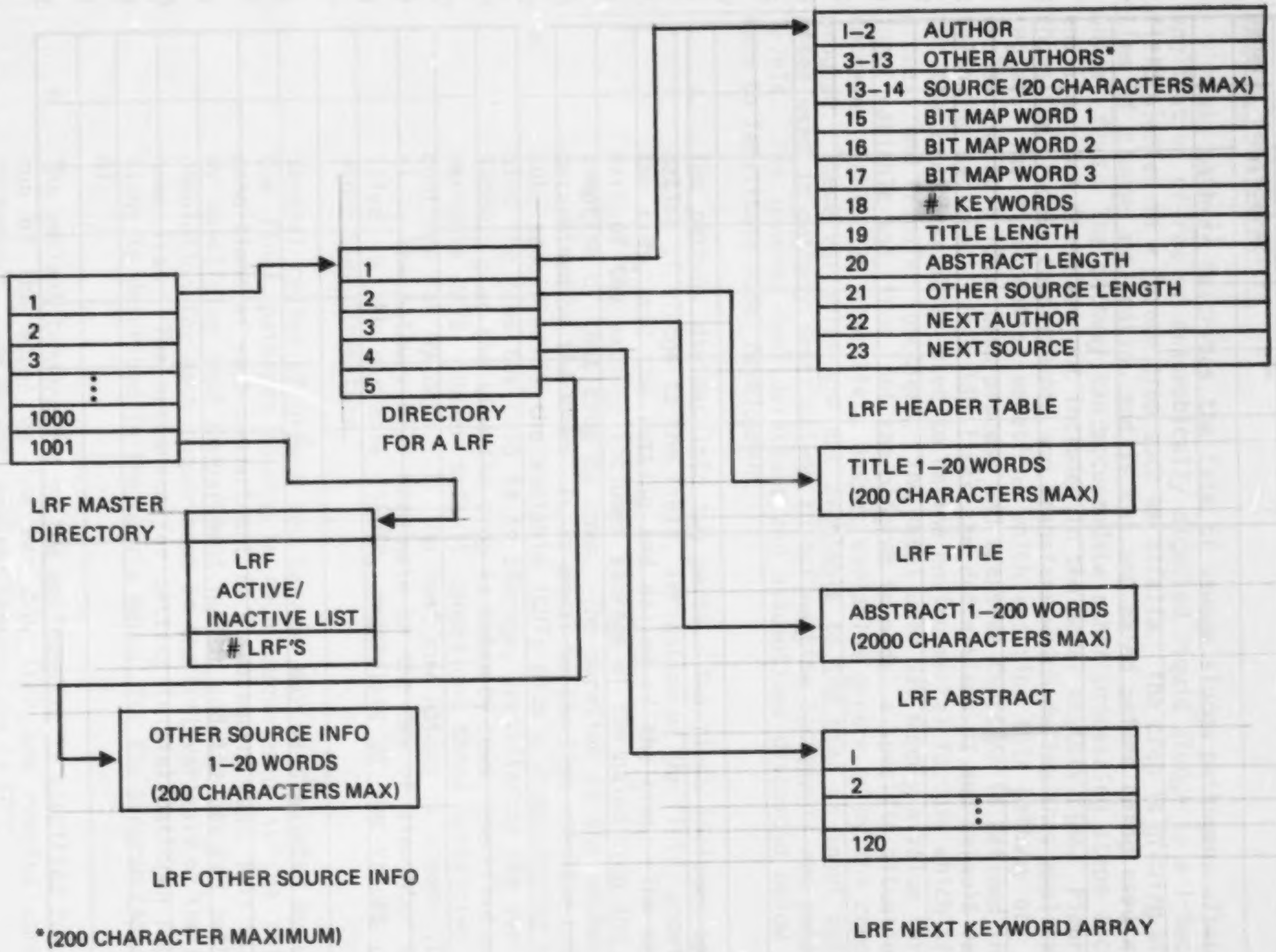
JOBA

TYPING GUIDE SHEET

BEGIN FIRST LINE OF

CENTER

TOP OF IMAGE


1-2 AUTHOR
3-13 OTHER AUTHORS*
13-14 SOURCE (20 CHARACTERS MAX)
15 BIT MAP WORD 1
16 BIT MAP WORD 2
17 BIT MAP WORD 3
18 # KEYWORDS
19 TITLE LENGTH
20 ABSTRACT LENGTH
21 OTHER SOURCE LENGTH
22 NEXT AUTHOR
23 NEXT SOURCE
LRF HEADER TABLE
1
2
3
⋮
1000
1001
LRF MASTER DIRECTORY
1
2
3
4
5
DIRECTORY FOR A LRF
TITLE 1-20 WORDS (200 CHARACTERS MAX)
LRF TITLE
LRF ACTIVE/ INACTIVE LIST
# LRF'S
ABSTRACT 1-200 WORDS (2000 CHARACTERS MAX)
LRF ABSTRACT
OTHER SOURCE INFO 1-20 WORDS (200 CHARACTERS MAX)
LRF OTHER SOURCE INFO
1
2
⋮
120
LRF NEXT KEYWORD ARRAY

*(200 CHARACTER MAXIMUM)

Figure B-13. Library data base structure - LRF File.

LAST LINE OF TEXT

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BOTTOM OF IMAGE AREA, SIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

Query File. This is because the LRF directory will contain pointers to all the LRFs contained in the data base. The LRF subindex will be nothing more than an information directory linking all the information together for a particular LRF.

The LRF Header Table contains information linking successive LRFs by author, source, and keyword as well as other information including author name, source name, and length of title and abstract. The Bit Map Words contained in the header table provide keyword information for a given LRF. Currently, 82 keywords have been identified for an LRF. In order to save on computer memory and expedite a keyword-directed search for an LRF, the keyword information has been compacted to two words. A CDC word is 60 bits in length; thus, two CDC words or 120 bits should be adequate for present needs. The bit location within the Bit Words will correspond to the Keyword Name List of the Query File. Thus, bit 45 will correspond to keyword 45 of both the Keyword Name List in Figure B-12 and the LRF Next Keyword Array shown in Figure B-13.

The LRFs are linked to each other by author, source, and keyword. For example, the computer word containing author information contains the record number in the LRF master directory that points to the location of another LRF with the same author name. The same information is maintained for sources and keywords. For the keywords, this information is contained in the LRF Next Keyword Array. Thus, when a new LRF is added to the data base, the last occurrence record for the same author, source, and keywords is updated to maintain the linked list. Corresponding information within the Query File is also updated to reflect the information from the new LRF.

The CDC MSIO routines were used in order to save memory space during program execution and to allow faster update access than is available in a sequential file system. However, the library data base may easily grow to a size that exceeds the amount of disk space allowed for a user on the Sandia system. Therefore, the data base is automatically placed on a sequential file so that the user may save the data base on magnetic tape after the last LRF transaction. The structure of the sequential LRF is described in the section detailing the new file driver.

LRF Transaction Driver

The structure of the LRF transaction driver by subroutine is illustrated in Figure B-14. The main function of this driver is to read LRF information from the Tektronix 4025 terminal and to decode the data into a form usable by the host computer. Subroutine LRFDRM sends the commands needed to create a form on the terminal. The user responds by filling in the appropriate blanks of the displayed form and sending the information to the host computer. The subroutine LRFELD decodes each field of the LRF into a form that can be used by the LDB driver for LRF entry into the LDB.

The subroutines LRFINT and LRFNIT initialize the named commons /IFORM/ and /LRFFLD/ which are documented in the appendix. These named commons hold the data from the LRF entry and are reinitialized prior to each LRF entered.

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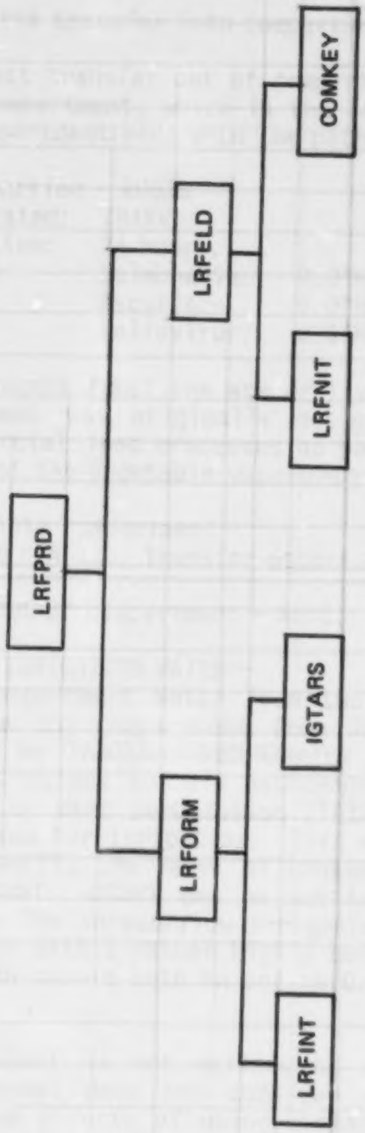
LRFPRD
LRFELD
COMKEY
LRFNIT
LRFORM
IGTARS
LRFINT

Figure B-14. LRF transaction driver subroutine structure.

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The subroutine IGTABS reads a user-input abstract and places the text and the abstract character length in named common /IFORM/. The subroutine COMKEY decodes the keyword section of an LRF and compresses this information into two words. This results in a preliminary keyword bit map that is used to determine the keywords contained in the entered LRF by the LDB driver.

LDB Driver

The main function of this driver is to update the LDB with the LRF data. The structure of this driver is shown in Figure B-15. The subroutine VLRFIL updates the LRF file by adding user-input LRF data to the LRF file. An error message will be displayed when the number of allowable LRFs is exceeded. This is currently set to 1000. The storage program terminates normally after issuing the error message:

```
**WARNING-LRF FILE IS FULL, THIS LRF CANNOT BE ADDED-
  TITLE-(up to 200 characters of title information)
  GET A PROGRAMMER TO EXTEND NAMED COMMON/LRFNDX/
```

Prior to extending named common /LRFNDX/ one should first determine the working size of the LDB for the user. If the user can work effectively on two or more smaller files, this is the recommended route to take. But if only a small number of LRFs are expected to be added, use the following procedure:

a. Determine the number of LRFs expected to be contained in the LDB.
b. The array LRFDIR contained in /LRFNDX/ should be redimensioned to the number of LRFs plus 2.
c. The array LRFLST contained in /LRFNDX/ should be redimensioned to the number of LRFs plus 1.
d. The variable MAXLRF contained in /LRFNDX/ should be updated in BLKDAT to reflect the number of LRFs in the LDB.
e. The variable LRFLEN contained in /LRFNODX/ should be updated in BLKDAT to reflect the LRFDIR array length.
f. The arrays LRFDIR and LRFLST should be initialized to the proper array lengths in BLKDAT.

If the above procedure is followed, the corrective action should extend the LDB for the storage program. No further action should be required to extend the LDB.

The subroutine UQRFIL updates the Query File by adding or updating the author and source information tables. As in the LRF file, these tables also have a finite length, but, unlike the LRF file, these tables can be adjusted in size to the user's needs. Currently, up to 600 author and 150 source names can be maintained. The storage program terminates normally after issuing either one of the following messages which include the title of the referenced LRF.

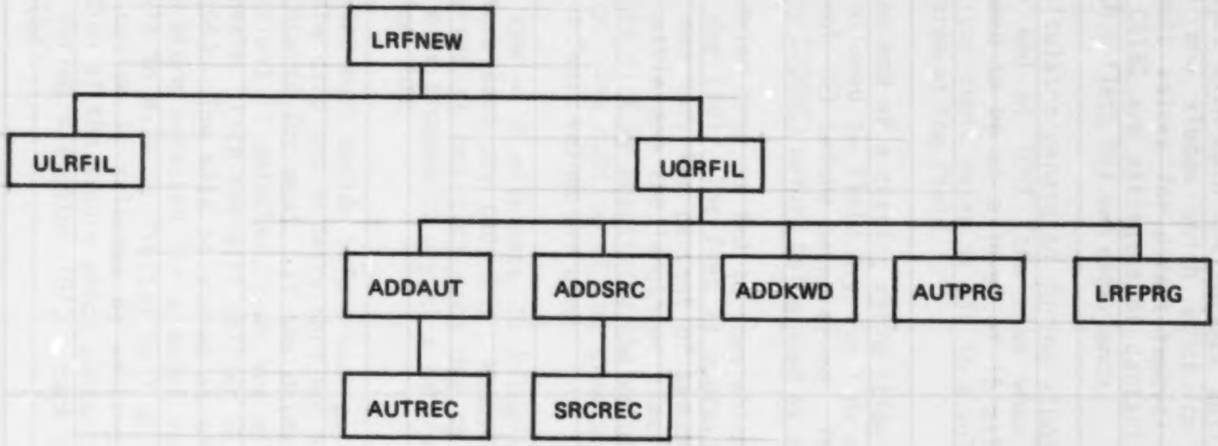
LRFNEW
ULRFIL
UQRFIL
ADDAUT
ADDSRC
ADDKWD
AUTPRG
LRFPRG
AUTREC
SRCREC

Figure B-15. LBD driver subroutine structure.

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```
    a.    **WARNING-AUTHOR NAME TABLE IS FULL**
                THIS LRF CANNOT BE ADDED--
          TITLE-(up to 200 characters of title information)
          GET A PROGRAMMER TO EXTEND NAMED COMMON/QRYNDX/
    b.    **WARNING-SOURCE NAME TABLE IS FULL**
                THIS LRF CANNOT BE ADDED--
          TITLE-(up to 200 characters of title information)
          GET A PROGRAMMER TO EXTEND NAMED COMMON/QRYNDX/
```

To extend either the author name table or source name table, use the following procedure:

a. Determine a working author or source name table length (this is generally two times the number of authors or sources to be expected).
b. The array IAUTH or ISRCE contained in /QRYNOX/ should be redimensioned to number of authors or sources plus 2.
c. The array NAMAUT or NAMSRC contained in /ARYNDC/ should be redimensioned by the following algorithm, length=2 * (number of authors or sources) + 1.
d. The variables MXAUTH and MXSRCE contained in /QRYNDX/ should be updated in BLKDAT to reflect the maximum number of authors and source names.
e. The arrays NAMAUT and NAMSRC should be initialized in BLKDAT.

9-1/8"

The above procedure extends the storage program to accept a user-defined author and source name table length for the LDB. No further action should be required to extend the LDB.

New File Driver

The primary function of the new file driver is to place the LDB on a master (centralized) sequential file. This driver creates a file as described in the Library Storage Program User's Guide (Section 2). The created file can be stored on the Sandia computer (by using the SAVE/REPLACE command) or placed on tape. For a large LDB it would be a good idea to use the latter procedure for backup purposes. This file may be updated by the storage program and queried by the retrieval program. The subroutine structure of this file is shown in Figure B-16.

COMPUTATIONAL PROCEDURES

The storage program is only concerned with data manipulation and flow. As such, all computational procedures are concerned with LRF data storage location, entry, and output.

Form Generator

The form generator portion of the storage program sends form generating commands to the Tektronix 4025 terminal. These commands are discussed in both of the Tektronix manuals: "4025 Operator's Manual" and "4025 Programmer's Reference Manual." To execute the storage program the

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

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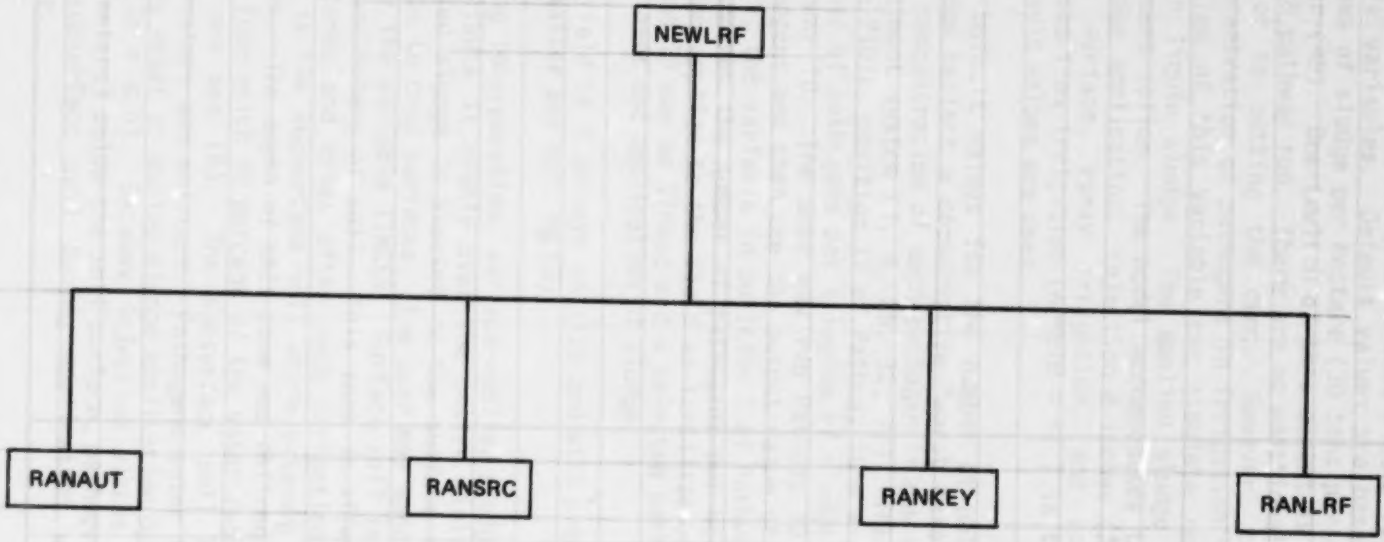
NEWLRF
RANAUT
RANSRC
RANKEY
RANLRF

Figure B-16. New file driver subroutine structure.

user must be sure the command LOCKOUT light on the terminal is off. If the light is on, the 4025 will not respond to the commands sent from the storage program.

The 4025 screen is 34 lines in length, of which 33 lines may be designated as workspace for forms processing. Since an LRF is greater than 33 lines in length, the LRF was divided into three sections. The first section of the LRF is 20 lines in length, the second section is 30 lines in length, and the last section does not use the workspace.

The user need not be concerned with the line length of the first two sections of the form. The abstract, however, must be limited to the first 70 characters of each line. Any additional characters will be lost. Since there is ample space (29 lines of text) for an abstract, this should not pose any inconvenience.

Program File Requirements

The storage program builds the master index/subindex indices internally through subroutine INIT. These master directories are written to TAPE91 and TAPE92. Also, if OLDLRF exists, the master directories are initialized with the OLDLRF information. The resultant master file is NEWLRF. Thus, prior to beginning a terminal session, the user should be sure that his local file space is clear, otherwise, a Record Manager error may result during the master index/subindex initialization process.

The other required files are as described in Table B-2.

SECTION B-4

LIBRARY RETRIEVAL PROGRAM USER'S GUIDE

The following section will relate all information required for the user to execute the retrieval program. It gives an overall statement of capabilities, followed by a definition of the input command language; then it describes the output and gives examples of runs and interactions between the parts of the system.

RETRIEVAL PROGRAM CAPABILITIES

The Library Retrieval Program is designed to access and retrieve information stored on the LIBRARY DATA BASE by the Library Storage Program. It formats the retrieved information and returns it to the user via the interactive terminal or a high speed line printer. The program is written in FORTRAN IV and runs under the FTN compiler on the CDC 6600 utilizing the NOS operating system.

By the use of a simple input command language, the user can search the data base; locate any, all, or none of the occurrences of an item; print them on the terminal or at the central computer site; or simply list out all or parts of the Library Data Base. The program was designed and written to provide the user with a direct, straightforward method of extracting information. Extensive error messages were incorporated into the code to provide the user with feedback if a faulty command should be entered. An interrupt capability was also included to stop display or printout and return control to the user. During output, an I, S, or double "break" typed in will interrupt processing and return the prompt character.

INPUT LANGUAGE

The Library Retrieval Program Query Language commands provide the user with the means to specify a search of the LRF data base and to print or display the results of the library search and the contents of the library. The Query Language commands have the same format; that is, these commands start with the command name which can then be followed by one or more options separated by commas. Each command is terminated by a semicolon. A detailed discussion of each Query Language command follows.

FIND

The FIND command is the instruction that the user encodes in order to specify the library search parameters. The general form for this instruction is:

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

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(4-76)

```
FIND   { ,KEY1=char1(char2)*  }
       { ,KEY2=char1(char2)   }
       { ,AUTHOR=achar        }  ;
       { ,SOURCE=schar        }
       { ,TITLE=tchar         }
       { ,COUNT=num           }
```

where

a. The keyword parameters KEY1 and KEY2 permit the user to specify a library search for LRFs containing these keywords. The variable char1 is the name of one of the nine primary LRF keywords. From the list of secondary keywords associated with the primary LRF keyword (specified by char1), the user must select a secondary keyword and set char2 equal to its name. The user is permitted to specify a maximum of two keyword parameters per FIND command.

b. The AUTHOR parameter provides the capability of searching the library for LRF entries for the named author. The variable achar is set equal to the author's last name, followed by a blank and terminated by the first letter of the author's first name.

c. The library search can be keyed on LRFs obtained from specific information sources by assigning a value to the variable schar in the parameter SOURCE. In Table B-4, an example of the correspondence between the full information source name and the abbreviated equivalent name is defined.

d. The parameter TITLE is used to specify a library search for an LRF with a particular title. The variable tchar is set equal to the desired title. With the exception of blanks, no punctuation is permitted in the title string.

e. The parameter COUNT can be used to bound the library search. The variable num can be set equal to an integer (>1) or the word ALL. The word ALL requests a search of the library for all occurrences of LRFs that meet the requirements specified by the parameters of the FIND command. If an integer value is assigned to the variable num, then the search is made for the integer number of occurrences specified. If the parameter COUNT is not defined, then the default value COUNT=1 is assumed.

f. The brackets are used to delineate the optional parameters of the FIND instruction and the optional parameters of all the remaining Query Language commands.

g. All Query Language commands must be terminated by a semicolon.

---

* Char 1 represents any one of the none primary keywords listed in Table 1.
Char 2 represents one of the corresponding keywords.

BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"

BEGIN
FIRST
TYPING GUIDE SHEET
CENTER
TOP OF
IMAGE
AREA

TABLE B-4. EXAMPLE SOURCE PARAMETER DEFINITIONS

NAME	SCHAR
APPLIED AND ENVIRONMENTAL MICROBIOLOGY	APPL ENVIRON MICROBIOL
INFECTION AND IMMUNITY	INFECT IMMUN
JOURNAL OF ENVIRONMENTAL QUALITY	J ENVIRON QUAL
JOURNAL OF THE WATER POLLUTION CONTROL FEDERATION	JWPCF
LANCET	LANCET
SLUDGE MAGAZINE	SLUDGE MAG
WATER RESEARCH	WATER RES

3/8"
FOR TABLES
AND ILLUS-
TRATIONS

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h. The output from the FIND command consists of the printout on the interactive terminal of the record number of the first occurrence of an LRF and the total number of occurrences of LRFs that meet the requirements specified in the FIND command. If the total number of occurrences is zero, then the library search was unsuccessful.

Examples of the FIND command are:

```
FIND,AUTHOR=ZEKE I, KEY1=TRANSPORT(INSECT);
```

This FIND instruction requests a library search for the first occurrence (since COUNT was omitted) of an LRF with the author I. Zeke and the secondary keyword INSECT checked in the TRANSPORT keyword list.

```
FIND,AUTHOR=LIPSCHITZ B,
TITLE=THE SURVIVAL OF TAENIA IN DISMAL SWAMPS,
KEY1=PATHOGENS(TAENIA), COUNT=1;
```

This FIND command requests a library search for the first occurrence of an LRF with the author B. Lipschitz, with the secondary keyword TAENIA checked in the PATHOGEN keyword list, and with the title "The Survival of Taenia in Dismal Swamps."

9-1/8"

DISPLAY

The DISPLAY command is used to print on an interactive terminal the LRFs found from a library search. A FIND command must precede a DISPLAY command. The general form for this instruction is:

```
DISPLAY   { ,COUNT=num }        ;
          { ,FORM=ALL  }
```

where

a. The parameter COUNT is used to specify the number of LRFs found from the library search (specified by the FIND command) to be printed. The variable num is defined in precisely the same manner as it is defined for the FIND command. In addition, the default value COUNT=1 is used.

b. The default printout for each LRF consists of the author, title, and keyword lists. If the user utilizes the option FORM=ALL, then the entire LRF is printed.

An example DISPLAY command is given by:

```
DISPLAY,COUNT=5;
```

In this example, a maximum of five LRFs will be printed with the default print format.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

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PRINT

The PRINT command is used to print on a line printer the LRFs found from a library search. A FIND command must precede a PRINT command. The general form for this instruction is:

```
PRINT  { ,COUNT=num }  ;
       { ,FORM=ALL  }
```

where the parameters and variables are the same as the parameters and variables for the DISPLAY command.

LIST

The LIST command provides the user with capability of dumping onto a line printer a subset of the contents of the entire library. The general form for this instruction is:

```
LIST  { ,AUTHOR }  ;
      { ,SOURCE }
      { ,TITLE  }
      { ,ALL    }
```

where

a. The selection of the AUTHOR option causes the printout of all the author names residing in the library.

b. The selection of the SOURCE option causes the printout of all the source document names for the entire library.

c. The selection of the TITLE option causes the printout of the title of every LRF stored in the library.

d. The selection of the ALL option causes the complete printout of every LRF stored in the library.

The command

```
LIST,AUTHOR;
```

would generate a printed list of all the author names in the library. It is important to note that the user is permitted to specify only one option per LIST command.

END

The END command is entered by the user to define the last input command to the Library Retrieval Program. The form for this instruction is:

```
END;
```

1/2"
9-1/8"
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

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As was previously mentioned, the Query Language commands are input through an interactive terminal while executing the Library Retrieval Program. This computer program is designed to prompt the user by printing a question mark when it is ready to accept an input command (i.e., a Query Language command). Each input record can contain a maximum of 80 characters. The user may input only one Query Language command per input record. However, a command can span more than one input record. The user is permitted to embed blanks within a command in order to provide for a more readable listing of his input commands. If the user commits a typing error while entering a command, the Library Retrieval Program will print a diagnostic message on the user's terminal and the user will be required to reenter the command.

OUTPUT DATA STRUCTURE

During any particular interactive computer terminal session with the Library Retrieval Program, the user may generate output which will be displayed on the terminal or be dumped to a high-speed line printer at the central computer site. This output is restricted to 70 characters across the page in both mediums so that truncation or wraparound of data will not occur on terminals of the shorter width. The standardized format also eliminates confusion which might result from retrieval of abstracts which were entered on an 80-character wide terminal and printed on a 132-character wide line printer. The intent was to display or print the data exactly as they were entered.

Terminal Displays

The DISPLAY command causes the retrieved abstracts to be dumped to the terminal. Since most terminals have a screen width or page width near 80 characters, a length of 7 computer words or 70 characters was chosen. If the default short form was selected, then only the AUTHOR, TITLE, and KEYWORD list for an entry in the data base is retrieved. Figure B-17 shows an example of the short format. The first word of a line is reserved for a header such as AUTHOR:, TITLE:, or KEYWORDS: and thus the data occupy words 2 through 7.

The long format, when chosen by the FORM=ALL optional parameter, is structured in the same way as is the short format, with the addition of OTHER AUTHORS, SOURCE, OTHER SOURCE information, and the ABSTRACT TEXT. Figure B-18 shows an example of the long format. To replay the abstract text back exactly as it was typed in from the storage program, the "ABSTRACT TEXT:" heading is printed and the abstract begins on the next line.

Line Printer Displays

Line printer displays are generated by the PRINT command or the LIST command. The PRINT command generated listing has exactly the same format for both the short and long forms as the DISPLAY command, the only difference being that it is routed to the line printer rather than the user's terminal. Only the first 70 columns will be utilized.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

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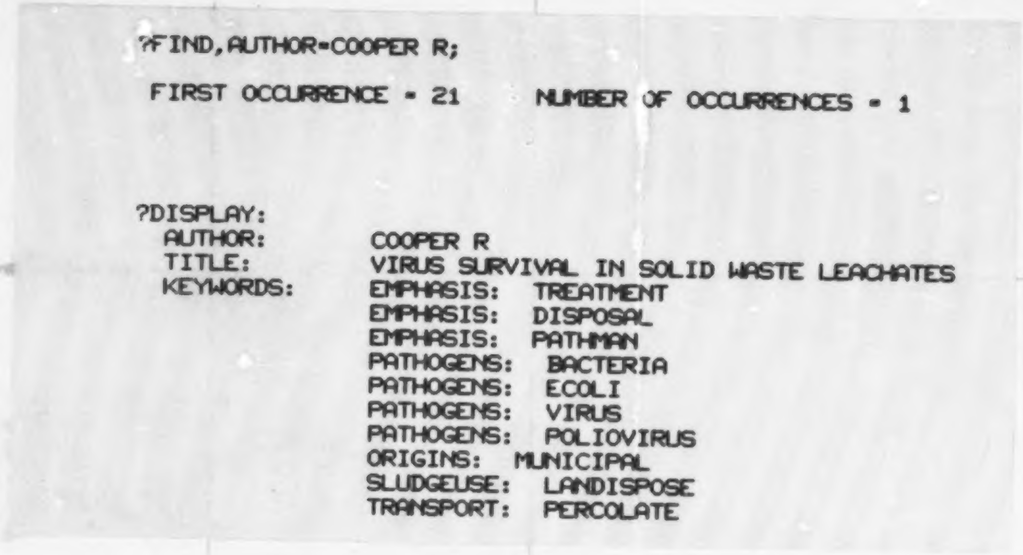


```
?FIND,AUTHOR=COOPER R;

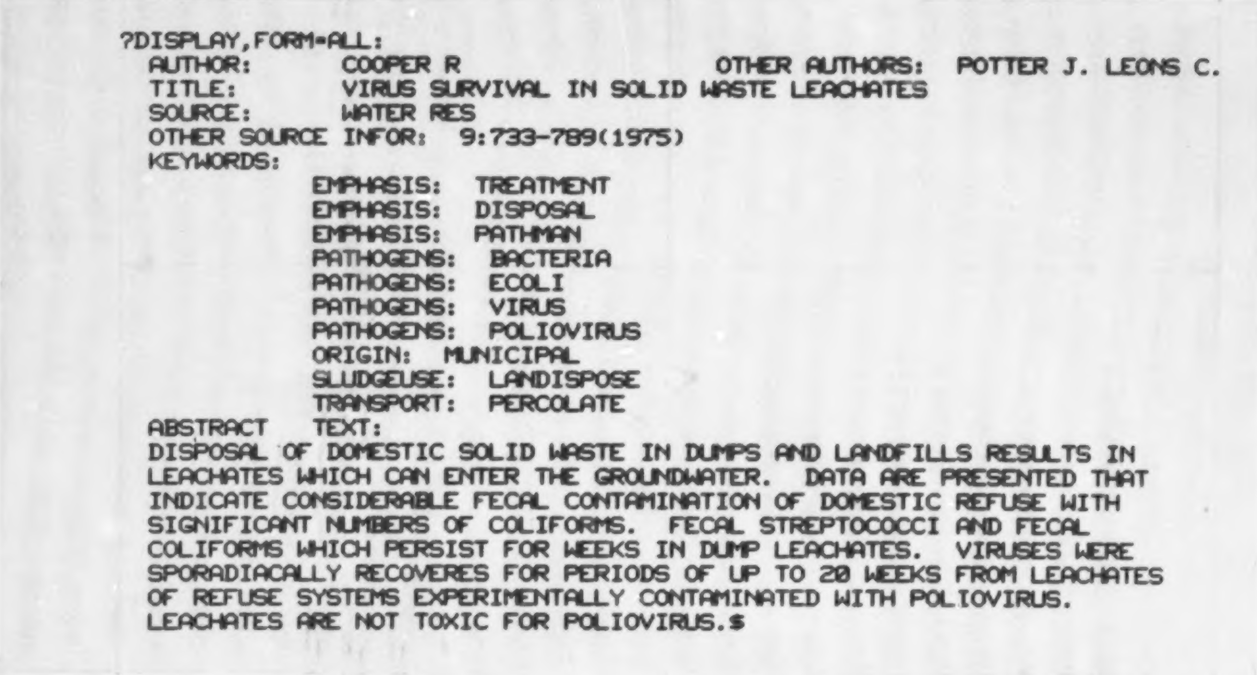
 FIRST OCCURRENCE = 21      NUMBER OF OCCURRENCES = 1


?DISPLAY:
  AUTHOR:          COOPER R
  TITLE:           VIRUS SURVIVAL IN SOLID WASTE LEACHATES
  KEYWORDS:        EMPHASIS:  TREATMENT
                   EMPHASIS:  DISPOSAL
                   EMPHASIS:  PATHMAN
                   PATHOGENS:  BACTERIA
                   PATHOGENS:  ECOLI
                   PATHOGENS:  VIRUS
                   PATHOGENS:  POLIOVIRUS
                   ORIGINS:  MUNICIPAL
                   SLUDGEUSE:  LANDISPOSE
                   TRANSPORT:  PERCOLATE
```

Figure B-17. Display command short format.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

EPA-287 (Cin.)
(4-76)



```
?DISPLAY,FORM=ALL:
  AUTHOR:       COOPER R                  OTHER AUTHORS:  POTTER J. LEONS C.
  TITLE:        VIRUS SURVIVAL IN SOLID WASTE LEACHATES
  SOURCE:       WATER RES
  OTHER SOURCE INFOR:  9:733-789(1975)
  KEYWORDS:
             EMPHASIS:  TREATMENT
             EMPHASIS:  DISPOSAL
             EMPHASIS:  PATHMAN
             PATHOGENS:  BACTERIA
             PATHOGENS:  ECOLI
             PATHOGENS:  VIRUS
             PATHOGENS:  POLIOVIRUS
             ORIGIN:  MUNICIPAL
             SLUDGEUSE:  LANDISPOSE
             TRANSPORT:  PERCOLATE
  ABSTRACT   TEXT:
  DISPOSAL OF DOMESTIC SOLID WASTE IN DUMPS AND LANDFILLS RESULTS IN
  LEACHATES WHICH CAN ENTER THE GROUNDWATER.  DATA ARE PRESENTED THAT
  INDICATE CONSIDERABLE FECAL CONTAMINATION OF DOMESTIC REFUSE WITH
  SIGNIFICANT NUMBERS OF COLIFORMS.  FECAL STREPTOCOCCI AND FECAL
  COLIFORMS WHICH PERSIST FOR WEEKS IN DUMP LEACHATES.  VIRUSES WERE
  SPORADIACALLY RECOVERES FOR PERIODS OF UP TO 20 WEEKS FROM LEACHATES
  OF REFUSE SYSTEMS EXPERIMENTALLY CONTAMINATED WITH POLIOVIRUS.
  LEACHATES ARE NOT TOXIC FOR POLIOVIRUS.$
```

Figure B-18. Display command long format.

BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
BEGIN LAST LINE OF TEXT
3/8"

PAGE NUMBER
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The LIST command has different formats for output depending on the option chosen. LIST, AUTHOR; and LIST, SOURCE; will only use two words or 20 characters on the line printer. LIST, TITLE; and LIST, ALL; can use up to 70 characters per line and may have multiple lines. Rows of asterisks are used to separate each item of output.

Interactive Messages

In response to certain commands, the retrieval program will issue messages to the user via the terminal. These messages can reflect the results of a search on the data base, a completion of a LIST or a PRINT command, or an interrupt from the user. These messages are informative and self-explanatory.

EXECUTING THE RETRIEVAL PROGRAM

The user wishing to retrieve information from the Library Data Base needs to perform some preliminary chores before executing the retrieval program. These tasks are summarized in sections below.

6-1/2"

Retrieval Program Hardware Requirements

Due to file size limitations under Sandia's NOS operating system, it was necessary to break up the LRF data base into separate files. These files are stored sequentially on magnetic tape via the TFILE system. The reader is referred to the NOS News Notes Number 15 for storage and retrieval of the files contained on this magnetic tape with code number 10146.

Once a part of the data base has been retrieved and is a permanent indirect-access file in the user's disk area, the retrieval program can be executed. For the PRINT and LIST commands the user is reminded that a high speed line printer is required.

Retrieval Program Cataloged Procedures

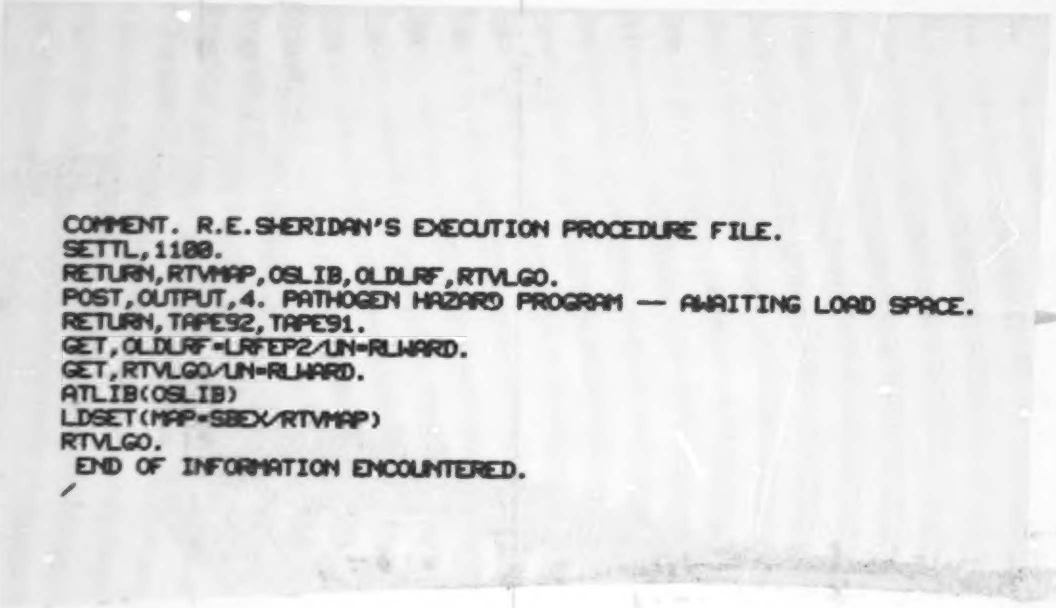
The retrieval program is executed from a relocatable binary file under the cataloged procedure, shown in Figure B-19. Hence, execution is automatic once the user types in -RES, the procedure file name. When the question mark prompt symbol is typed, the user can proceed with input language commands. Before execution of the cataloged procedure, it is mandatory that the data base file name (as retrieved from the TFILE magnetic tape for processing) matches exactly the file name in the cataloged procedure on line 6. In this example, file LRFEP2 should have been pulled off the TFILE tape 10146 and placed in user RLWARD's disk area. Otherwise, this line should be changed to reflect the true file name under consideration.

Example: If the command

```
TFILE,RECALL,10146,LRFEPA
```

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

EPA-287 (Cin.)
(4-76)



```
COMMENT. R.E.SHERIDAN'S EXECUTION PROCEDURE FILE.
SETTL,1100.
RETURN,RTVMAP,OSLIB,OLDLRF,RTVLGO.
POST,OUTPUT,4. PATHOGEN HAZARD PROGRAM -- AWAITING LOAD SPACE.
RETURN,TAPE92,TAPE91.
GET,OLDLRF=LRFEP2/UN=RLWARD.
GET,RTVLGO/UN=RLWARD.
ATLIB(OSLIB)
LDSET(MAP=SBEX/RTVMAP)
RTVLGO.
 END OF INFORMATION ENCOUNTERED.
/
```

Figure B-19. Execution procedure file.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

EPA-287 (Cin.)
(4-76)

was executed previously to place file LRFEPA into RLWARD's disk area, then line 6 of the procedure should read:

```
GET,OLDLRF=LRFEPA/UN=RLWARD.
```

The execute the retrieval program while making changes to the code, the cataloged procedure -JFD can be used. Figure B-20 lists this procedure and once again line 6 should reflect the appropriate data base file name. The file UPDJD contains a permanent copy of UPDATE corrections the user wishes to make. There is, then, the opportunity to add temporary corrections, inspect the entire recreated code (but not modify it at this point), and then compile and execute.

By eliminating the COMMENT. at appropriate lines in the procedure, the user can inspect the MAP, the DAYFILE, and local file spaces. CSLIB is required to provide the terminal interrupt routines, and the file MAPMOD contains XEDIT commands to locate error conditions in the MAP.

The user may obtain hard copy listings of the retrieval program by using the procedure -MASTER. Figure B-21 lists this procedure. In addition to a FORTRAN listing, a complete UPDATE master audit is dispatched along with a load map.

Responses to Prompts and Commands

The first response of the Library Retrieval program is the message, "**LIBRARY RETRIEVAL PROGRAM --AWAITING LOAD SPACE**." When space is found the program will return with a prompt character, "?". The user then types (on the line next to the prompt character) the first query or command, ending it with a semicolon. Hitting the return key sends the command to the computer. The program will respond to each command with either the information requested or a clearly worded error message. Error messages are more fully discussed in the Problems/Error Message subsection. If the program returns a prompt character without any explanation, check the end of the command to see if the necessary semicolon was omitted. Long commands containing several options can be input by typing one line of information and returning. Then wait for the prompt before continuing to type the rest of the command on the next line. The program will evaluate the command only after receiving the terminating semicolon.

After responding to each command, the program will return the prompt character to signal readiness to accept the next command. When the user wishes to end a retrieval session, he types "END;" after the prompt. The program will return with, "EXECUTION OF THE LIBRARY RETRIEVAL PROGRAM COMPLETED," followed by a computer usage message and the prompt character, "/". Whenever the "/" prompt is returned, the Library Retrieval Program is no longer active. Note that a semicolon follows the end command. If the semicolon is not typed, the program will return a prompt "?" as explained above.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

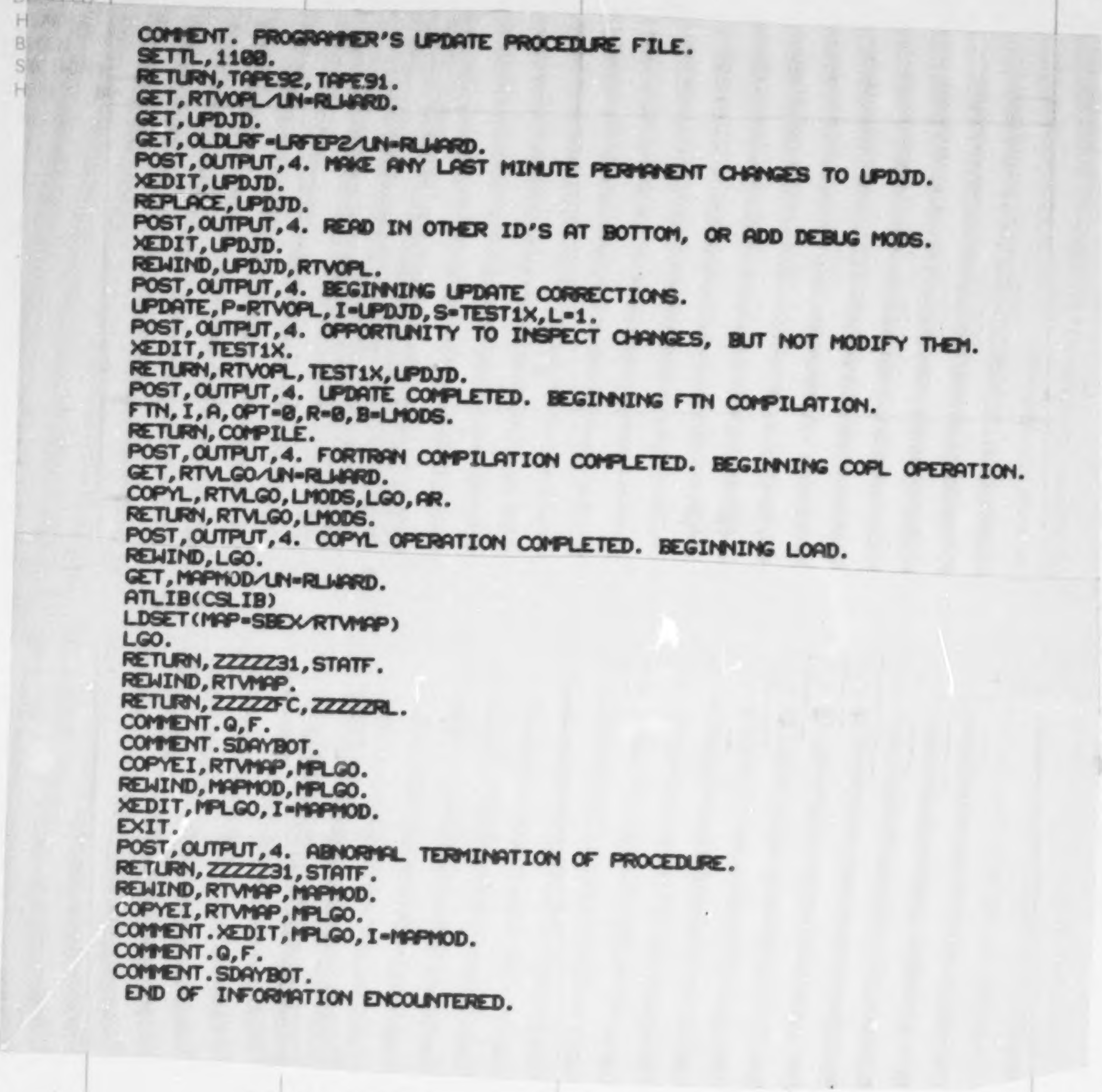
EPA-287 (Cin.)
(4-76)

BEGIN
FIRST
LINE OF
TEXT
HERE

TYPING GUIDE SHEET

CENTER
OF PAGE

TOP OF
IMAGE
AREA



```
COMMENT. PROGRAMMER'S UPDATE PROCEDURE FILE.
SETTL,1100.
RETURN,TAPE92,TAPE91.
GET,RTVOPL/UN=RLWARD.
GET,UPDJD.
GET,OLDLRF=LRFEP2/UN=RLWARD.
POST,OUTPUT,4. MAKE ANY LAST MINUTE PERMANENT CHANGES TO UPDJD.
XEDIT,UPDJD.
REPLACE,UPDJD.
POST,OUTPUT,4. READ IN OTHER ID'S AT BOTTOM, OR ADD DEBUG MODS.
XEDIT,UPDJD.
REWIND,UPDJD,RTVOPL.
POST,OUTPUT,4. BEGINNING UPDATE CORRECTIONS.
UPDATE,P=RTVOPL,I=UPDJD,S=TEST1X,L=1.
POST,OUTPUT,4. OPPORTUNITY TO INSPECT CHANGES, BUT NOT MODIFY THEM.
XEDIT,TEST1X.
RETURN,RTVOPL,TEST1X,UPDJD.
POST,OUTPUT,4. UPDATE COMPLETED. BEGINNING FTN COMPILATION.
FTN,I,A,OPT=0,R=0,B=LMODS.
RETURN,COMPILE.
POST,OUTPUT,4. FORTRAN COMPILATION COMPLETED. BEGINNING COPL OPERATION.
GET,RTVLGO/UN=RLWARD.
COPYL,RTVLGO,LMODS,LGO,AR.
RETURN,RTVLGO,LMODS.
POST,OUTPUT,4. COPYL OPERATION COMPLETED. BEGINNING LOAD.
REWIND,LGO.
GET,MAPMOD/UN=RLWARD.
ATLIB(CSLIB)
LDSET(MAP=SBEX/RTVMAP)
LGO.
RETURN,ZZZZZ31,STATF.
REWIND,RTVMAP.
RETURN,ZZZZZFC,ZZZZZRL.
COMMENT.Q,F.
COMMENT.SDAYBOT.
COPYEI,RTVMAP,MPLGO.
REWIND,MAPMOD,MPLGO.
XEDIT,MPLGO,I=MAPMOD.
EXIT.
POST,OUTPUT,4. ABNORMAL TERMINATION OF PROCEDURE.
RETURN,ZZZZZ31,STATF.
REWIND,RTVMAP,MAPMOD.
COPYEI,RTVMAP,MPLGO.
COMMENT.XEDIT,MPLGO,I=MAPMOD.
COMMENT.Q,F.
COMMENT.SDAYBOT.
 END OF INFORMATION ENCOUNTERED.
```

Figure B-20. Update catalogued procedure.

BEGIN
LAST LINE
OF TEXT

BOTTOM OF
IMAGE AREA
OUTSIDE
DIMENSION
FOR TABLES
AND ILLUS-
TRATIONS

3/8"

PAGE NUMBER

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(4-76)

BEGIN FIRST LINE OF TEXT HERE
TYPING GUIDE SHEET
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD: BEGIN SECTION HERE

```
COMMENT. MULTIPLE LISTING PROCEDURE.
CLEAR.
SETTL,1100.
GET,RTVOPL/UN=RLWARD.
GET,NIL/UN=RLWARD.
UPDATE,F,P=RTVOPL,I=NIL,O=LIST,L=F.
RETURN,RTVOPL,NIL.
RA.
PRINT,LIST.
RETURN,LIST.
POST,OUTPUT,4. MASTER AUDIT DISPATCHED.
FTN,I,L=LIST,R=3,B=LMODS,P.
RETURN,COMPILE.
POST,OUTPUT,4. NO FATAL ERRORS IN FORTRAN COMPILATION.
RA.
PRINT,LIST.
POST,OUTPUT,4. MASTER DISPATCHED.
LDSET(MAP=SBEX/RTVMAP)
LOAD,LMODS.
NOGO.
RA.
COPYEI,RTVMAP,MPLGO.
RETURN,RTVMAP.
RA.
PRINT,MPLGO.
POST,OUTPUT,4. LOAD MAP DISPATCHED.
RETURN,LMODS.
Q,F.
EXIT.
POST,OUTPUT,4. PROCEDURE ABNORMALLY TERMINATED - CALL PROGRAMMER.
SDAYBOT.
Q,F.
 END OF INFORMATION ENCOUNTERED.
/
```

Figure B-21. Master catalogued procedures.

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

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Example Run

Step 1. Log Into Computer System --

The library retrieval program is designed to be run from either a graphics terminal or an alphanumeric terminal with the output of PRINT and LIST commands going to a line printer. The user at either remote terminal would phone the computer and, after establishing a line, log in with an appropriate user number and password. The program is run in an interactive mode. The prompt character "/" indicates that the system is ready to receive a command.

Example:

```
6000 SYSTEM UP

79/07/04.    10.46.39.
SANDIA NOS SN53 ECS                      NOS 1.2-460
USER NUMBER, PASSWORD

TERMINAL:  11, TTY
RECOVER/SYSTEM:  BATCH
$RFL,0.
/
```

Step 2. Load Library Retrieval Program --

To load the Library Retrieval Program, the user types "-RES" after the prompt character "/" and hits the return key. The program will respond with a load message. The return of a prompt character, "?", indicates that the program is loaded and ready for the first retrieval command. There may be a long wait between load message and prompt.

Example:

```
/-RES
LIBRARY RETRIEVAL PROGRAM--AWAITING LOAD SPACE*
?
```

Step 3. Retrieval Commands --

Once the program is loaded, the user must plan his search. The first step in using any computerized information system is to become familiar with the keywords used in indexing stored information. After reviewing the list, the user chooses those terms which most nearly define the area of information he is seeking. A table listing the keywords for the sludge pathogen hazard project may be found in Section 1. Suppose the user wishes to find articles on how polioviruses are affected by certain sludge treatment regimes, particularly anaerobic digestion. The keywords from the list which define this area are: Emphasis (Treatment), Emphasis (Pathman), Pathogens (Virus), Pathogens (Poliovirus), and Treatment (Anaerobic). Since the Library Retrieval Program permits two keywords to be cross-referenced in a command, the user might decide to start by searching for abstracts indexed by both Emphasis (Treatment) and Pathogens (Virus). The user would type, after the prompt, a FIND command containing both keyword options and specifying these keywords.

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Example:

```
    ? FIND,KEY1=PATHOGENS(VIRUS),KEY2=EMPHASIS(TREATMENT);
    FIRST OCCURRENCE = 4    NUMBER OF OCCURRENCES = 1
    ? FIND,KEY1=PATHOGENS(VIRUS),KEY2=EMPHASIS
    ? (TREATMENT),COUNT=100;
    FIRST OCCURRENCE = 4    NUMBER OF OCCURRENCES = 17
```

Note the differences in the two example FIND commands and the responses to each. The first FIND command does not contain a COUNT option. When count is not specified it defaults to one. Therefore, response to this command indicates that the fourth abstract in the file being searched is indexed by both specified keywords and that only one such abstract was found since the program stopped looking after finding count one. The second FIND command contains a specified COUNT option. Because this command statement is longer, it was split between two lines. Note that a prompt character, signalling the readiness of the program to receive information, must proceed each command line and that the program waits for the terminating character ";", a semicolon, before processing any part of a command. The response to the second command indicates, once again, that the fourth abstract in the file is indexed by both keywords. The second part of the response indicates that 17 abstracts in the file are indexed by both keywords. The count option in the second command is the number of abstracts known to be in the particular file being searched. Since the count may be any arabic numeral up to six digits, a very large number may be used when file length is unknown.

A FIND command must always proceed a DISPLAY or PRINT command. These commands allow the user to look at abstracts in the file. The DISPLAY command causes the abstracts retrieved by a FIND command to be sent to the remote terminal at which the user is working. The PRINT command sends the same information to a line printer. Since the same information is returned by both commands, the DISPLAY command will be used as an example for both. Any of the following DISPLAY commands would allow the user to see the abstracts located by the FIND command given above:

```
    ? DISPLAY;
    ? DISPLAY,FORM=ALL;
    ? DISPLAY,COUNT=5;
    ? DISPLAY,COUNT=17,FORM=ALL;
```

Neither COUNT nor FORM options are specified in the first command so both would default. The default format includes the AUTHOR, TITLE, and KEYWORD fields of an abstract. In this case, the default form of the first abstract found to contain the keywords specified in the FIND command would be returned.

Example:

```
    ? DISPLAY;
    AUTHOR:   KOTT Y
    TITLE:    BACTERIOPHAGES AS VIRAL POLLUTION INDICATORS
    KEYWORDS: EMPHASIS:  SURVIVAL
              EMPHASIS:  TREATMENT
```

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```
                    EMPHASIS:  PATHMAN
                    EMPHASIS:  OTHER
                    PATHOGENS:  BACTERIA
                    PATHOGENS:  VIRUS
                    PATHOGENS:  POLIOVIRUS
   ?
```

The second command listed above would return the entire abstract since the FORM is specified as ALL, but since the COUNT is not specified and is therefore one, only the first abstract in the file meeting the keyword requirements of the proceeding FIND command would be returned.

Example:

```
? DISPLAY,FORM=ALL;
AUTHOR:  KOTT Y                    OTHER AUTHORS: FOZE N, SPERBER S, B
ETZER N
TITLE:  BACTERIOPHAGES AS VIRAL POLLUTION INDICATORS
SOURCE:   WATER RES
OTHER SOURCE INFO:  8:165-174(1974)
KEYWORDS: EMPHASIS:   SURVIVAL
          EMPHASIS:   TREATMENT
          EMPHASIS:   PATHMAN
          EMPHASIS:   OTHER
          PATHOGENS:  BACTERIA
          PATHOGENS:  VIRUS
          PATHOGENS:  POLIOVIRUS
ABSTRACT TEXT:
F2 PHAGE AND ATTENUATED POLIOVIRUS STRAIN L (LSC) WERE INTRODUCED
DAILY INTO A 350 L EXPERIMENTAL OXIDATION POND.  SYSTEM SHOWED NO
DECREASE IN BACTERIAL VIRUS F2, THE OTHER COLIPHAGE OR POLIOVIRUS.
RATIOS OF COLIPHAGE TO HUMAN ENTERIC VIRUS RANGED FROM 1 TO 1 - 10
TO THE 5TH TO 1 IN VARIOUS WATERS AND EFFLUENTS.  IN THREE EPIDEMICS
OF ENTERIC DISEASE CAUSED BY WATER SUPPLY, THE WATER SUPPLY WAS
POSITIVE FOR COLIPHAGE,  IN 2 CASES SUPPLY WAS ALSO POSITIVE FOR
ENTERIC VIRUS.$
?
```

The third command would return the short, default form of the first five abstracts located by the FIND command. The last DISPLAY command given above would return the entire abstract for all 17 abstracts located in the file. Usually, a command such as the third is used, specifying a count as large as the file. Then, the user can rapidly scan titles to locate relevant articles.

The abstract used as an example shows that when a limited number of keywords are used to index a large number of articles in a very diverse data base, retrieval operations may return many unusable items while finding the desired ones. The user might wish to be more specific in the choice of keywords in the FIND command and, for example, use Pathogens (Poliovirus) and Treatment (Anaerobic). With either set of keywords the following part of the return would have been of interest:

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE
9-1/8"
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"
PAGE NUMBER
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```
AUTHOR:   PALFI A
TITLE:    SURVIVAL OF ENTEROVIRUSES DURING ANAEROBIC SLUDGE
          DIGESTION
KEYWORDS: EMPHASIS:   SURVIVAL
          EMPHASIS:   TREATMENT
          EMPHASIS:   PATHMAN
          PATHOGENS:  VIRUS
          PATHOGENS:  COXSACKIEB
          PATHOGENS:  ECHOVIRUS
          PATHOGENS:  POLIOVIRUS
          PATHOGENS:  REDVIRUS
          ORIGIN:     MUNICIPAL
          TREATMENT:  ANAEROBIC
?
```

The next step, of course, is to look at the complete entry for this article. This short form is part of a long DISPLAY return. In order to look at the whole form, another FIND command must be used. This command could specify either the title or the author of the article. Specifying the title and using a COUNT option would not only locate this article for a DISPLAY but would get information on other articles by the same author.

Example-

```
? FIND,AUTHOR=PALFI A,COUNT=100
FIRST OCCURRENCE = 44     NUMBER OF OCCURRENCES = 1
? DISPLAY,FORM=ALL;
AUTHOR:  PALFI A     OTHER AUTHORS:
TITLE:   SURVIVAL OF ENTEROVIRUSES DURING ANAEROBIC SLUDGE DIGESTION
SOURCE:  PROCEEDINGS
OTHER SOURCE INFO:  6TH INTERNATIONAL CONFERENCE ON WATER POLLUTION
RESEARCH, ADVANCES IN WATER POLLUTION RESEARCH,  PROCEEDINGS HELD
IN JERUSALEM IN 1972, PUB 1973, P99-104
KEYWORDS: EMPHASIS:   SURVIVAL
          EMPHASIS:   TREATMENT
          EMPHASIS:   PATHMAN
          PATHOGENS:  VIRUS
          PATHOGENS:  COXSACKIEB
          PATHOGENS:  ECHOVIRUS
          PATHOGENS:  POLIOVIRUS
          PATHOGENS:  REDVIRUS
          ORIGIN:     MUNICIPAL
          TREATMENT:  ANAEROBIC
 ABSTRACT TEXT:
AN EFFORT WAS MADE TO ASSESS THE VIROLOGICAL EFFICIENCY OF ANAERO-
BIC EQUIPMENT OPERATING AT A WASTE WATER TREATMENT PLANT IN
BUDAPEST.  FOR THIS PURPOSE QUALITATIVE VIROLOGICAL EXAMINATIONS
WERE CARRIED OUT ON 74 DIGESTED SLUDGE SAMPLES IN 1969.  IN 1970,
FOLLOWING THE MODIFICATION OF THE DIGESTION PROCEDURE, A FURTHER
82 SAMPLES WERE EXAMINED FOR ENTEROVIRUS DENSITY.  THE EFFECTS ON
VIRUS SURVIVAL OFR VARIOUS CONDITIONS OF DIGESTION (TEMPERATURE,
DURATION OF TREATMENT) WERE COMPARED.$
?
```

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No other articles by this author are in the file presently being queried by the Library Retrieval Program but the abstract indicates that this article will definitely give the user information on how poliovirus are affected by anaerobic digestion. The user might now try to locate other papers from the conference listed as the source of this article by using the TITLE option in a FIND command. Had the source been a journal, the user could query using the accepted abbreviation of the journal name in a FIND command.

A PRINT command could have been used to look at complete abstracts for all 17 articles located in the original FIND command.

Example-

```
? FIND,KEY1=PATHOGENS(VIRUS),KEY2=EMPHASIS(TREATMENT),
? COUNT=100;
FIRST OCCURRENCE = 4    NUMBER OF OCCURRENCES = 17
? PRINT,FORM=ALL;COUNT=17;
PRINT COMMAND COMPLETED
?
```

A print command writes information to a file, LPRNT. This operation is shown by the return of a message indicating the command is complete. The abstracts are not, however, actually printed out until after the user has left the Library Storage Program and requests the LPRNT file to be printed. This operation is discussed in Step 5.

The other possible query command of the Library Retrieval Program is LIST. Like the PRINT command, LIST writes information to a file, LPRNT, and the information is sent to a line printer when requested (see Step 5). The LIST command does not return information located in a FIND command. It lists information which is part of the abstract file internal index: all authors, all sources, or all titles; or lists the entire contents of the file. If the user wishes to look at every abstract in a file, he uses a LIST command.

Example:

```
? LIST,ALL;
LIST COMMAND COMPLETED
    ?
```

Step 4. Leaving Library Retrieval Program --

To leave the Library Retrieval Program after finding needed information, type "END;" next to the prompt character "?". The program will return a computer usage message and the prompt character, "/".

Example:

```
?END;
EXECUTION OF THE LIBRARY RETRIEVAL PROGRAM COMPLETED
     2.721 CP SECONDS EXECUTION TIME
/
```

BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA; OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
3/8"

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Step 5. Getting Print and List Information to the Line Printer --

After leaving the Library Retrieval Program, follow standard computer system rules for printing the file LPRNT. This file contains the information retrieved in any PRINT or LIST command executed during the entire retrieval session.

Example:
```
/ RA
/ PRINT,LPRNT
PRINT,LPRNT.
/
```

Step 6. Log Off Computer --

The last line in the example for Step 5 indicates that any information in the LPRNT file has gone to the line printer. The user can now log off the computer by typing "BYE" next to the prompt.

Example:
```
/BYE
10.45.10 79/07/05.
OFF RLWARD
TTY 027   9.848 SRU
```

Problems/Error Messages

There are over 50 different possible error messages and comments which can be returned by the Library Retrieval Program. Each is fairly self-explanatory. In order to simplify identification of program problems, error messages and comments were grouped by general type. Below is a list of these groupings. Examples of the type of error message or comment which might be sent is given and a discussion of why it was sent and what to do.

Problems With Length--
```
"AUTHOR NAME TOO LARGE, STATEMENT IGNORED"
"TOO MANY CHARACTERS IN PRIMARY KEYWORD"
"OPTIONS EXCEED ALLOWABLE NUMBER FOR THIS COMMAND,
  STATEMENT IGNORED"
```

There is a character limit for each field in the LRF which is searchable by the Library Retrieval Program. The AUTHOR and SOURCE fields may not exceed 20 characters and the TITLE field may not exceed 200 characters. The length of a keyword is limited to nine characters. If any of these limits are exceeded in a retrieval command a length error message like those above will be returned. Author names, article titles, and journal names are truncated and/or abbreviated according to set rules when entered on an LRF form. These rules should be reviewed before trying to find an abstract. Remember, the Library Retrieval Program matches information in a retrieval command letter by letter against information in the abstract files. If a name was truncated when entered on an LRF form, it must be truncated in exactly the same way in a retrieval command for a match to be recognized.

TYPING GUIDE SHEET
BEGIN FIRST LINE OF TEXT HERE
CENTER OF PAGE
TOP OF IMAGE AREA
DROPPED HEAD; BEGIN SECTIONS HERE
6-1/2"
BEGIN LAST LINE OF TEXT
BOTTOM OF IMAGE AREA, OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
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Each type of command has an allowable number of options. As stated in the input language section, six options including two keywords, an author, a source, a title, and the count may be specified in a FIND command. Two options - count and form - may be specified in the DISPLAY and PRINT commands. Four options - author, source, title, or all - may be specified in a LIST command. If more options are given in any command statement, an error message stating this is printed. Check the command line to see that only allowable options have been used and that no option has been unintentionally repeated.

Problems With Symbols or Punctuation Marks--

```
     "PREMATURE SEMICOLON ENCOUNTERED, STATEMENT IGNORED"
     "INVALID SYMBOL - FOUND IN COMMAND NAME, STATEMENT IGNORED"
     "COMMAND OPTION NAME MAY NOT START WITH A DIGIT,
       STATEMENT IGNORED"
```

Only three punctuation marks and one symbol are allowed in library retrieval commands. A comma separates options, a semicolon is used to terminate a command, parentheses surround secondary keywords, and an equal sign is used to link generic options and the specific item sought. The use of any other punctuation marks or symbols or the misplacement of these four will result in an error message such as given in the first two messages above. Check command carefully to see that punctuation is correct. Noise on the line can be misread as an unallowable character. Always delete a command statement and retype it if a noise sequence intrudes.

The third error message above refers to the use of arabic numerals in commands. The count option must be followed by an arabic numeral. The title of an article may contain an arabic numeral but not as the first character. The author name and source fields should not contain numbers.

Problems With Illegal Commands--

```
     "ILLEGAL COMMAND OPTION, STATEMENT IGNORED"
     "INVALID SPECIFICATION OF LRF KEYWORD, STATEMENT IGNORED"
     "NON-EXISTENT QUERY COMMAND, STATEMENT IGNORED"
```

The most common reason for this type of error message is the misspelling of a command option or the intrusion of noise into a command. Carefully check the format of the command statement and then retype. Any time noise appears in a command or a mistake is made in typing, it is best to delete that line by hitting the escape key and then retype the command on the next line.

Not Found--

```
     "AUTHOR NOT FOUND"
```

When the specific item being searched for is not found, the system returns a comment like the above. Sometimes this comment will be returned when the user knows that the item is in the file. First check the spelling in the retrieval command. Even one wrong letter will lead to a non-match. If spelling is correct, check spacing. The program compares position by position, character by character. The most common spacing error occurs in

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long titles which must be typed on several lines. If a word ends on the first line, space once after return to leave the first position on the next line blank. If spelling and spacing are correct, it is advisable to search for the known abstract by another means, such as by specifying a known keyword. Sometimes mistakes occurred in the entry of abstract-identifying information. If an author name is misspelled in the file, the query command must also misspell the name.

Other Specific Error Messages or Comments--
"DISPLAY/PRINT NOT PROCEEDED BY FIND COMMAND,
STATEMENT, IGNORED"

The PRINT and DISPLAY commands must be proceeded by a FIND command which locates the information to be displayed or printed.

"INCOMPLETE LRF KEYWORD SPECIFICATION,
STATEMENT IGNORED"

The keyword options of the FIND command have two parts. The user must specify both the primary keyword which indicates a group and the secondary keyword which is a member of that group.

"*--DISPLAY/PRINT COMMAND ABORTED BY USER INTERRUPT--*"

It is possible to interrupt the return of a DISPLAY, PRINT or LIST command by hitting the interrupt key. The above comment will be returned. The interrupted command must be reentered if further file information is sought. The reentry of a DISPLAY or PRINT command must be proceeded by a FIND command.

"PRINT COMMAND COMPLETED"

After the completion of a list or print operation, a comment such as the above is returned. The user may continue with retrieve operations.

Fatal Error Message--
"FATAL ERROR 78, ILLEGAL DATA IN FIELD"

Anytime the prompt character "/" is returned, the Library Retrieval Program is no longer active. To reactivate the program, type -RES. The error message above will be returned when anything other than an arabic number is specified in the COUNT option. Occasionally, noise on the line may result in a fatal error.

Dispatching Created Files

After completion of an interactive terminal session, the user will have created a local file if the PRINT or the LIST commands were executed. This local file, called LPRNT, is the output from the retrieval program which is to be sent to the line printer. However, this file can be treated as any local file under NOS and can be examined under XEDIT, or by the use

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of the COPYCF command. To send the file to the line printer, the user would execute the following commands:

```
REWIND,LPRNT
COPYSBF,LPRNT,LIST
PRINT,LIST
```

The listing could then be picked up in Box 671 at the Sandia Laboratories' Central Computing facility.

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SECTION B-5

LIBRARY RETRIEVAL PROGRAMMER/ANALYST GUIDE

The LIBRARY RETRIEVAL PROGRAMMER/ANALYST GUIDE is intended to provide the programmer/analyst with a comprehensive insight into the program structure, subsystem interaction, and computational procedures that comprise the Library Retrieval Program. In this way, modification and enhancement to the code is facilitated.

PROGRAM OVERVIEW

The Retrieval Program reads from TAPE89, the sequential LRF DATA BASE, and constructs the random access master indices. One index, TAPE91, is the master for the LRF directory while the other, TAPE92, is the master for the QUERY file. The reader is referred to the Programmer/Analyst Guide for the Library Storage Program (Section B-3) for more detailed information on the Library Data Base Structure. Once the main driver has done this, along with initializing the interrupt capability by a call to TERMINT, control is passed to the PARSER/SYNTAX ANALYZER segment where it remains until the user ends the program.

The retrieval program requires 55K octal to load on the CDC 6600 and runs under the NOS BE level 1 operating system. It is written in FORTRAN IV and compiles with SANDIA's FTN compiler. Wherever possible, the attempt was made not to utilize site-specific modules but in some cases, such as the terminal interrupt routine, this was unavoidable.

PROGRAM STRUCTURE

The program structure of the Library Retrieval Program is essentially divided into two parts. The first is the Input Language Processing Subsystem which translates user-supplied commands into computer coded directives to the second subsystem. The second subsystem uses these coded commands to query the Library Data Base via CDC's mass storage random access I/O routines. TAPE91 and TAPE92, created by SUBROUTINE OLDLRF, are the master directories for these system routines. These subsystems are presented in greater detail below.

Query Language Processing Subsystem

Query Language Definition--
The Library Retrieval Program Query Language provides the user with the capability of specifying a search of the LRF data base and of printing or displaying the results of the data base search.

The Query Language commands can be expressed mathematically as a context free language which is generated by the context-free grammer G. The context-free grammer G is defined by the following standard set:

$$G = \{V_N, V_T, P, S\}$$

where

a. V_N is the set of nonterminal symbols:
{capital letters of the alphabet.}

b. V_T is the set of terminal symbols:
{small letters of the alphabet, blanks, the digits 0 through 9, comma, semicolon, parentheses, equal sign.}

c. P is the set of productions from which the Query Language commands are generated.

d. S is the start symbol. $S \varepsilon V_N$.

The usual production format for representing grammars is used. Each production is of the form:

$$A \rightarrow \alpha$$

where A is a nonterminal symbol and α is a string of nonterminal and/or terminal symbols. The vertical " " is used as a shorthand notation (essentially representing a logical "or"). For example, the production

$$A \rightarrow B|CD|E$$

is equivalent to the following productions:

$A \rightarrow B$
$A \rightarrow CD$
$A \rightarrow E$

Each production of the context-free grammar is labeled (or identified) by an integer. Finally, it should be noted that this grammer is an LR(1) grammer. The following is the grammar that generates the Query Language:

1. S → ;
2. S → A;
3. A → B
4. B → find C
5-6. C → D | CD
7. D → ,key1=cstring
8. D → ,key1=cstring(cstring)
9. D → ,key2=cstring
10. D → ,key2=cstring(cstring)
11. D → ,source=cstring
12. D → ,title=cstring

13. D → ,author=astring
14. D → X
15. B → display E 16.-17. E → F|EF
18. F → X
19. F → Y
20. B → print G 21.-22. G → H|GH
23. H → X
24. H → Y
25. B → list I 26.-29 I → ,author|,source|,title|,all
30. B → end 31.-32. X → ,count=integer|,count=all
33. Y → ,form=all

where

cstring - is any string of characters excluding punctuation characters).

astring - is a character string (excluding punctuation characters) used to define an author's name.

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integer - integer constant (>1).

A diagram showing the structure of the Query Language Processing Subsystem is presented in Figure B-22. A description of each software module depicted in this figure is included in the appendix. A detailed discussion of the parsing, syntax analysis, and semantic analysis of Query Language commands performed by PARSYN (and associated modules) is presented in the next two sections of this report.

The PARSYN Program--

The algorithm implemented in the PARSYN module to parse Query Language commands is based on a mathematical representation of a DPDA (deterministic pushdown automaton). Thorough discussions of DPDAs can be found in numerous technical books (e.g., THE THEORY OF PARSING, TRANSLATION, AND COMPILING, by A. Aho and J. Ullman) and, therefore, only a brief discussion of a DPDA is presented in this report.

A pushdown automaton is a 7-tuple,

$$P=(Q,\Sigma,\Gamma,\delta,q_0,Z_0,F),$$

where

a. Q is a finite set of state symbols representing the possible states of the finite state control.

b. Σ is a finite input alphabet.

c. Γ is a finite alphabet of pushdown list symbols.

d. δ is a mapping from $Q \times (\Sigma \cup \{e\}) \times \Gamma$ to the finite subsets of $Q \times \Gamma^*$ (the symbol * denotes set closure, and e denotes the empty string).

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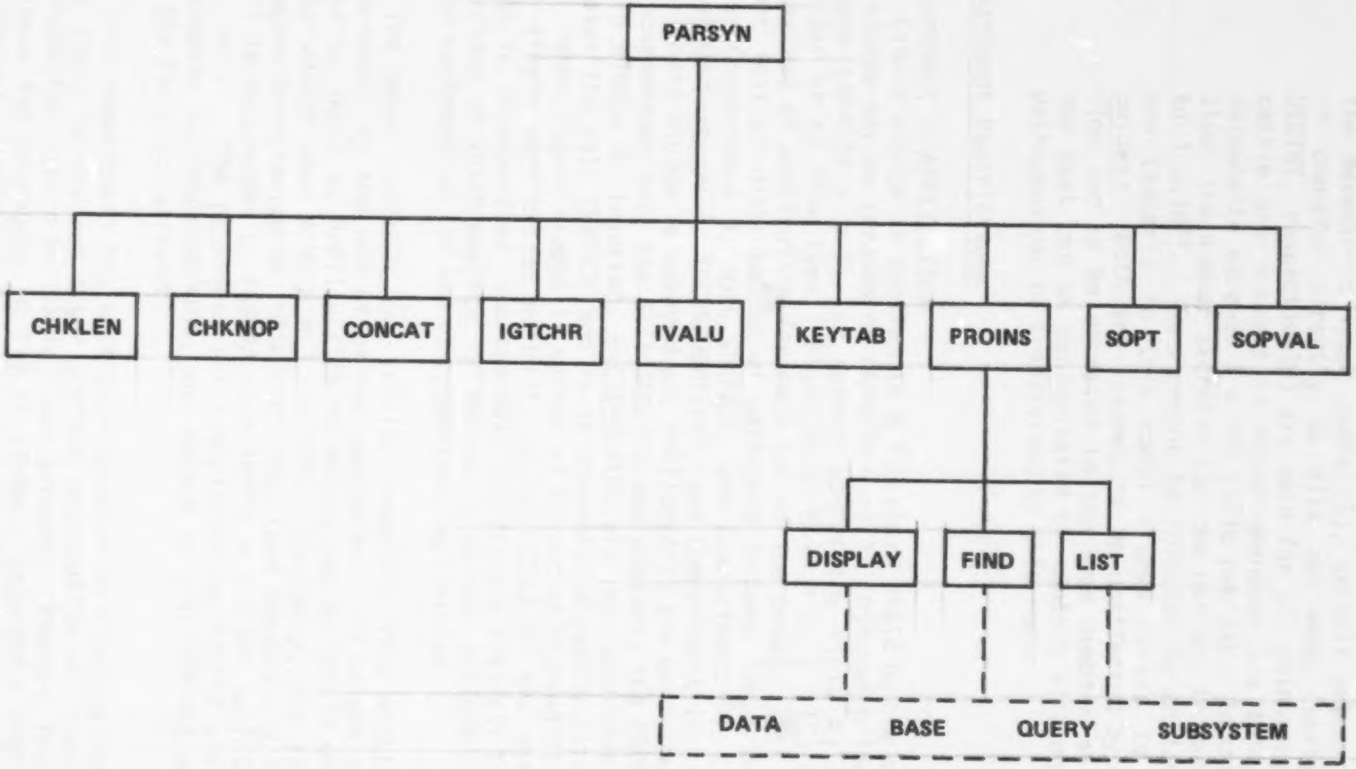
PARSYN
CHKLEN
CHKNOP
CONCAT
IGTCHR
IVALU
KEYTAB
PROINS
SOPT
SOPVAL
DISPLAY
FIND
LIST
DATA BASE QUERY SUBSYSTEM

Figure B-22. Query language processing subsystem.

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e. q_o ε Q is the initial state of the finite control.

f. Z_o ε Γ is the symbol that appears initially on the pushdown list (the start symbol).

g. F Q is the set of final states.

A pushdown automaton P is a DPDA if for each q ε Q and Z ε Γ either

a. δ (q,a,Z) contains at most one element for each a in Σ and δ (q,e,Z) = φ (empty set), or

b. δ(q,a,Z) = φ for all a ε Σ and δ(q,e,A) contains at most one element.

A diagrammatic representation of a DPDA is shown in Figure B-23. A configuration of P is a triple (q,w,α) in Q X Σ* X Γ*, where

a. q represents the current state of the finite control.

b. w represents the unused portion of the input. The first symbol of w is under the input head. If w = e, then it is assumed that all of the input tape has been read.

c. α represents the contents of the pushdown list. The leftmost symbol of ∝ is the topmost pushdown symbol. If α = e, then the pushdown list is assumed to be empty.

By way of analogy, the PARSYN algorithm can be directly related to the previously defined DPDA as follows:

a. The finite state control is embodied in the main processing loop which is flowcharted in Figure B-24.

b. The set Σ is equal to V_T which was defined in the previous section.

c. The mapping function w is defined by the state transition matrix (STM) in Figure B-25.

d. The set of state symbols q is identified by the STM row labels.

e. The pushdown list symbols Γ are defined by V_T. The PARSYN variables that are used as pushdown stacks are KEYSTR, OPSTR, PARSTR and SPRSTR. Each of these variables are singly-dimensioned arrays used to store variable length strings. By convention, all of these arrays must be a minimum of two words. The first word is used to store the string length (number of symbols) and the remaining words are used to store the string symbols (left justified).

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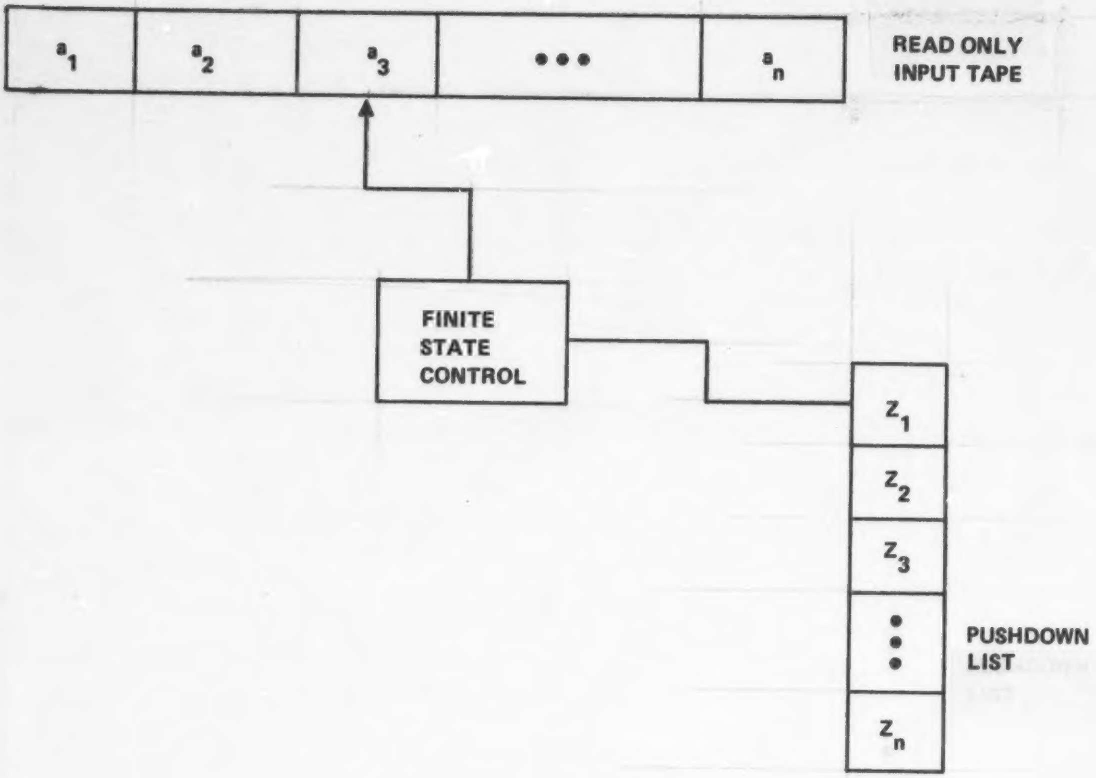

a_1
a_2
a_3
• • •
a_n
READ ONLY INPUT TAPE
FINITE STATE CONTROL
Z_1
Z_2
Z_3
•
•
•
Z_n
PUSHDOWN LIST

Figure B-23. Deterministic pushdown automation.

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TYPING GUIDE SHEET

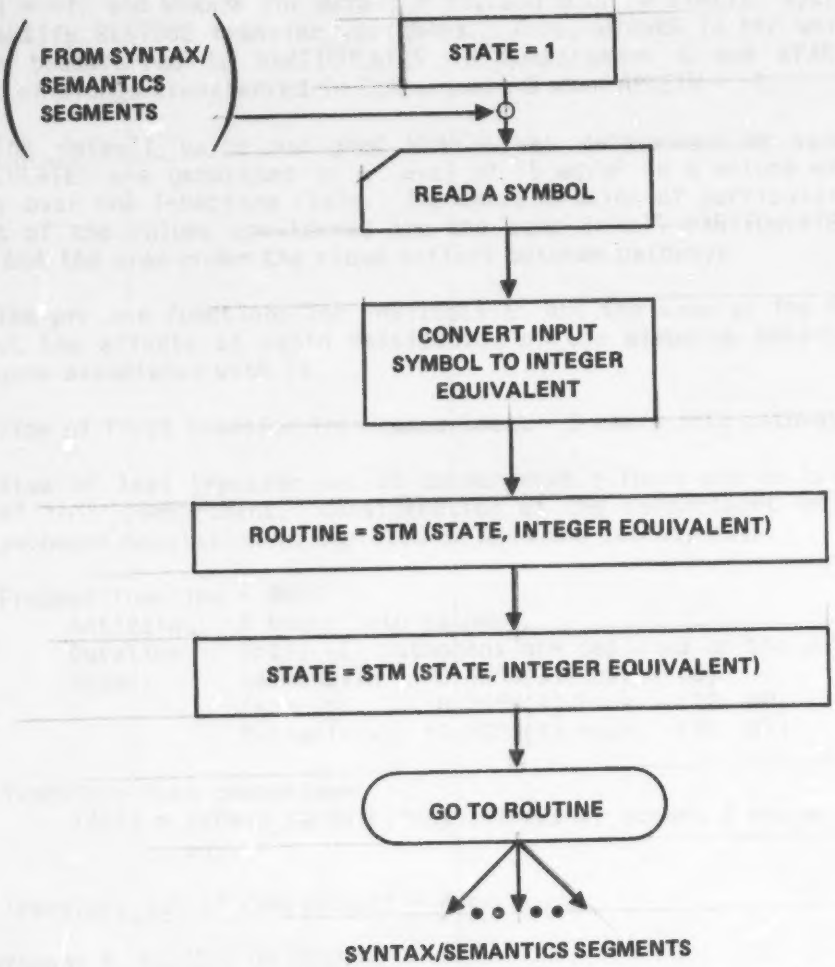
FROM SYNTAX/ SEMANTICS SEGMENTS
STATE = 1
READ A SYMBOL
CONVERT INPUT SYMBOL TO INTEGER EQUIVALENT
ROUTINE = STM (STATE, INTEGER EQUIVALENT)
STATE = STM (STATE, INTEGER EQUIVALENT)
GO TO ROUTINE
SYNTAX/SEMANTICS SEGMENTS

Figure B-24. PARSYN main processing loop.

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INPUT SYMBOL →

NEXT STATE / ROUTINE — STATE ↓	A–Z	0-9	&	.	;	(	)	=	OTHER
① START IDENTIFIER	2 INKEY	1 ERR1	1 CONT	1 ERR2	1 NULL	1 ERR2	1 ERR2	1 ERR2	1 ERR3
② COLLECT IDENTIFIER	2 CONKEY	2 CONKEY	3 CONT	4 SETKEY	1 ENULL	1 ERR2	1 ERR2	1 ERR2	1 ERR3
③ POSSIBLE KEYWORD	2 IMBED1	2 IMBED1	3 CONT	4 SETKEY	1 ENULL	1 ERR2	1 ERR2	1 ERR2	1 ERR3
④ START OPTION	5 INOPT	1 ERR4	4 CONT	1 ERR5	1 ENULL	1 ERR5	1 ERR5	1 ERR5	1 ERR3
⑤ COLLECT OPTION	5 CONOPT	5 CONOPT	6 CONT	1 ERR5	1 LIST	1 ERR5	1 ERR5	7 SETOPT	1 ERR3
⑥ POSSIBLE OPTION END	5 IMBED2	5 IMBED2	6 CONT	1 ERR5	1 LIST	1 ERR5	1 ERR5	7 SETOPT	1 ERR3
⑦ START PARAMETER	8 INPAR	8 INPAR	7 CONT	1 ERR6	1 PNULL	1 ERR6	1 ERR6	1 ERR6	1 ERR3
⑧ COLLECT PARAMETER	8 CONPAR	8 CONPAR	9 CONT	4 SOTICO	1 SOTIC1	10 SERPAR	1 ERR6	1 ERR6	1 ERR3
⑨ POSSIBLE PARAMETER END	8 COMPAR1	8 CONPAR1	9 CONT	4 SOTICO	1 SOTIC1	10 SETPAR	1 ERR6	1 ERR6	1 ERR3
⑩ START SECONDARY KEYWORD	11 INSKY	1 ERR7	10 CONT	1 ERR8	1 ERR8	1 ERR8	1 SENULL	1 ERR8	1 ERR3
⑪ COLLECT SECONDARY KEYWORD	11 COLSKY	11 COLSKY	12 CONT	1 ERR8	1 ERR8	1 ERR8	13 SESKEY	1 ERR8	1 ERR3
⑫ POSSIBLE SECONDARY KEYWORD END	11 COLSK1	11 COLSK1	12 CONT	1 ERR8	1 ERR8	1 ERR8	13 SESKEY	1 ERR8	1 ERR3
⑬ CHECK FOR END OF FIND	1 ERR9	1 ERR9	13 CONT	4 CHKID	1 COMEND	1 ERR9	1 ERR9	1 ERR9	1 ERR3

Figure B-25. Query language state transition matrix.

An explanation of the Query Language command processing algorithm which has been derived from Figure B-24, is presented in summary form by the steps below:

a. The initial state of the finite state control of the DPDA is set to the first state ("Start Identifier" of the STM).

b. An input symbol from the user's input command is read. (The symbols are read sequentially from left to right along the "Read Only Input Tape".)

c. The input symbol is next converted to an integer and then classified in one of the groupings that correspond to a column of the STM. On the CDC 6600 computer, the integer equivalent corresponds to the Display Code which is a unique integer value that is used to represent the symbol in memory.

d. The STM cell that is defined by the intersection of the STATE (i.e., row) and input symbol column number provides the symbolic address of a syntax/semantics routine (or segment) to branch to and an integer corresponding to the next finite control state (or STM row) to continue the compilation of the Query Language command.

e. The syntax/semantics routine is branched to. This routine is responsible for performing a syntactic analysis of the parsed string. In addition, if the input symbol is a semicolon, then the syntax/semantics segment performs a semantic analysis of the parsed command; that is, it branches to an appropriate module in the Data Base Query Subsystem to execute the user's search or print request. The syntax/semantics routines are INKEY, CONT, NULL, CONKEY, SETKEY, ENULL, IMBED1, INOPT, CONOPT, LIST, SETOPT, IMBED2, INPAR, PNULL, CONPAR, SOTICO, SOTIC1, SETPAR, CONPAR1, SENULL, COLSKY, SESKEY, COLSK1, CHKID, COMEND, ERR1, ERR2, ERR3, ERR4, ERR5, ERR6, ERR7, ERR8, ERR9, END, CHKLEN, CHKNOP, CONCAT, IGTCHR, IVALU, KEYTAB, PROINS, SOPT, SOPVAL, DISPLY, FIND and LIST.

f. After the syntax/semantics segment completes its function, control is passed to step (2) and the process is repeated until all of the user's input has been processed/compiled and executed by the semantics segments.

During the parse, syntax, and semantics analyses, integer values or opcodes are assigned to various fields encountered in a command. Table B-5 provides a summary of these opcodes for Query Language commands. The use of these opcodes effects an appreciable savings in computer memory and execution efficiency compared with the use/storage of the character strings.

DATA BASE QUERY SUBSYSTEM

The DATA BASE QUERY SUBSYSTEM is composed of three drivers which process the coded commands received from the INPUT LANGUAGE PROCESSING

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TABLE B-5. QUERY LANGUAGE OPCODES

Instructions:	INOPC	(PARSYN variable name)
FIND	1	
DISPLAY	2	
PRINT	3	
LIST	4	
END	5	

Options:	OPOPC	(PARSYN variable name)
KEY1	1	
KEY2	2	
AUTHOR	3	
SOURCE	4	
TITLE	5	
COUNT	6	
ALL	7	
FORM	8	

Parameters:*	PAROPC	(PARSYN variable name)
ALL	1	
OTHER	2	

*The Parameter field consists of the symbols to the right of the equal sign in an option field.

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subsystem, query the LIBRARY DATA BASE, format the output if any, and return control back to SUBROUTINE PARSYN. During execution, they utilize various program utilities to accomplish this, and they also report any possible errors arrived at while using the CDC MSIO utilities. Each of these drivers is explained in greater detail below.

FIND DRIVER--
The subroutines which comprise the FIND DRIVER are illustrated in Figure B-26. These are the routines which handle the actual search into the LIBRARY DATA BASE. ANDOPR is called by FNDRVR only if there exists more than one search attribute, as defined by the ICODE variable. ANDOPR performs an "AND" operation on records which are found by the other subroutines to assure that each LRF record meets all the requirements of the search. FNKEYS, FNSRCE, FNTITL, and FNAUTH return the first, last, and total number of occurrences of keywords, sources, titles, and authors, respectively, when a search on strictly that attribute is requested. When multiple attributes are desired, such as a keyword and an author, then FNDRVR finds the first occurrence of that attribute which comes first in the ICODE array and uses it as a starting point for the thread through the data base. ANDOPR then deletes any records added to the list which do not meet all of the search criteria. The appendix documents each subroutine's specific function in the retrieval program.

DISPLAY/PRINT DRIVER--
The subroutines which comprise the DISPLAY/PRINT DRIVER are illustrated in Figure B-27. These routines operate on the list of LRF records built by the FIND DRIVER to gather and format data to be output. There is a short format of output which only shows the AUTHOR, TITLE, and KEYWORD fields of an LRF entry. This form is a default condition and is controlled by the routine IGETIT. When the parameter FORM=ALL is added to a DISPLAY or PRINT command, then DPDRVR passes control to IGETIT which gathers information for the long form. The long form is the entire LRF entry. Finally, DPDRVR will select the terminal or the line printer for output (depending on the command). The appendix documents the function of each individual routine in the driver.

LIST DRIVER--
The subroutines which comprise the LIST DRIVER are illustrated in Figure B-28. Its purpose is to dump out authors, sources, titles, or all of the LIBRARY DATA BASE entries. This also can be interrupted by the user during execution. The format of the dump for the entire LRF is the same as that for the DISPLAY/PRINT DRIVER. The appendix documents the function of each of these routines.

Utilities

A number of subroutines perform duties which are called upon and utilized by the majority of subsystems within the retrieval program. These utilities are discussed below and the subroutines which comprise them are documented in the appendix.

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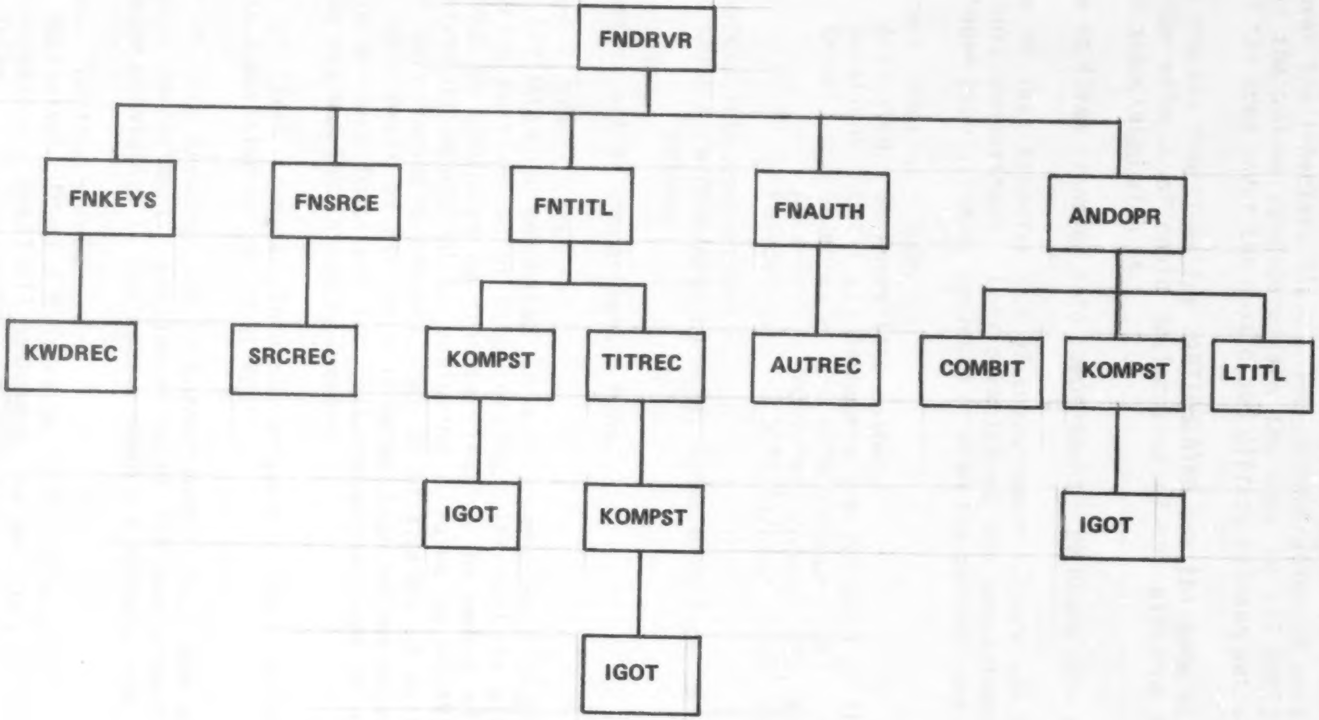
FNDRVR
FNKEYS
FNSRCE
FNTITL
FNAUTH
ANDOPR
KWDREC
SRCREC
KOMPST
TITREC
AUTREC
COMBIT
KOMPST
LTITL
IGOT
KOMPST
IGOT
IGOT

Figure B-26. Find driver associated subroutines.

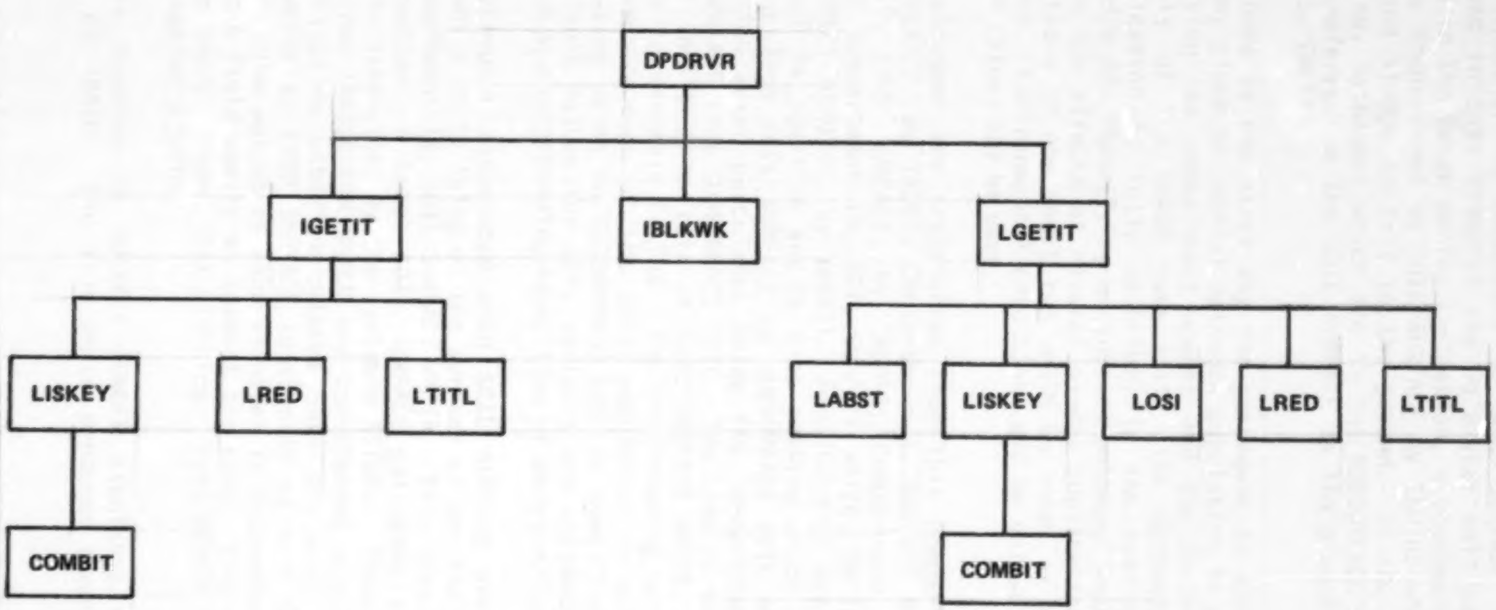
DPDRVR
IGETIT
IBLKWK
LGETIT
LISKEY
LRED
LTITL
COMBIT
LABST
LISKEY
LOSI
LRED
LTITL
COMBIT

Figure B-27. Display/Print drive associated subroutines.

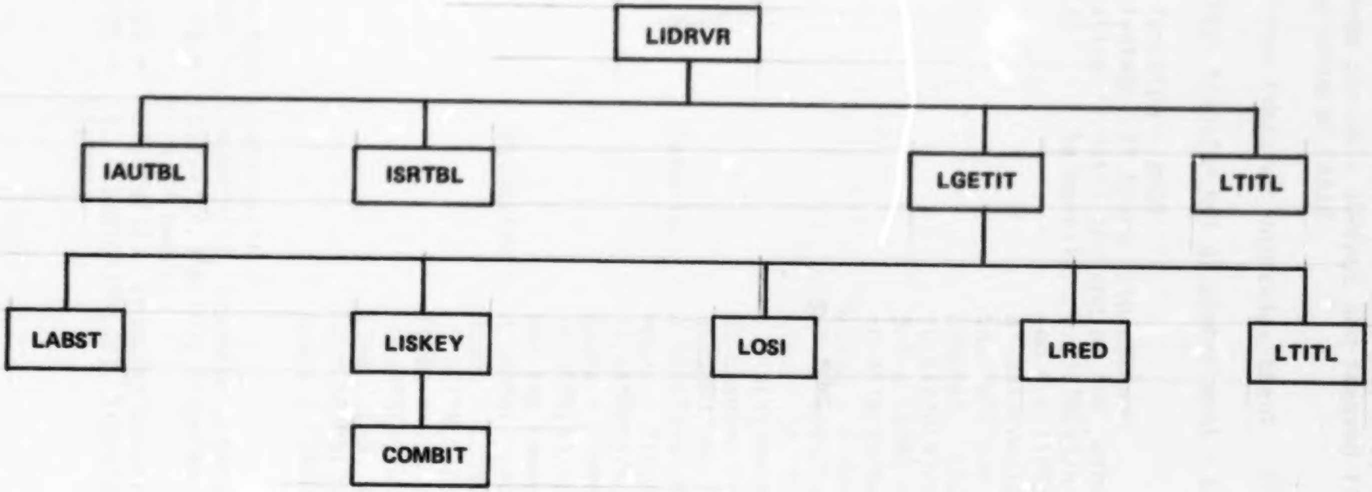
LIDRVR
IAUTBL
ISRTBL
LGETIT
LTITL
LABST
LISKEY
COMBIT
LOSI
LRED
LTITL

Figure B-28. List driver associated subroutines.

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Bit Map Expander--

This utility is composed of routines LISKEY and COMBIT. COMBIT determines if a match exists between the keyword list of an LRF in the data base and the keyword which is being sought in the search command. This is done by shifting and masking the bit map in the LRF until the bit position is the same as the keyword number. If the bit is set in the bit map for the position specified by the keyword in the search, LISKEY then writes out the associated character string and increments the keyword list counter. Each of the first 82 bits in the two-word bit map corresponds to a unique keyword from the Literature Review Form. Figure B-29 gives an example of the mapping.

String Comparison--

This utility is composed of routines KOMPST and IGOT. IGOT extracts characters one at a time from a string and returns them to KOMPST. KOMPST then determines exactly at what positon the strings vary. If they match, the position at which they vary is defined to be zero.

COMPUTATIONAL PROCEDURES

The Retrieval Program's computational procedures consist of data manipulation and flow. One major concern is the location of any particular entry in the Library Data Base from a FIND command. Then on a DISPLAY, PRINT, or LIST command the data are formatted for output, interrupts are handled, and external files may be created. The following sections discuss these areas.

LRF Address Calculation

The FIND DRIVER (described in the previous subsection) is responsible for creating a list of pointers from which the DISPLAY/PRINT DRIVER can locate the individual LRFs and print them out. To do this, the CDC mass storage I/O routines, READMS and STINDX, are used. These indices are retrieved in the opposite order from which they were stored.

Terminal Screen Format Setup

It was decided to utilize only 70 characters to avoid truncation or wraparound of data when information is displayed on a terminal screen. The same format was kept for the line printer to avoid confusion. The Author, Source, and Keyword lists need only two words so the remainder of the line is filled with blanks. The Title or Abstract Text, which is usually greater than 70 characters, is continued on successive lines until all information is displayed. Routines IGETIT and LGETIT format the data for display.

Interrupt Processing

The initial call to TERMINT in module RETRV permits the program to handle interrupts from the keyboard. This capability is only active when data are being dumped out and only when I, S, or double "break" keys are typed. All other keys have no effect. Because of the nature of the CDC

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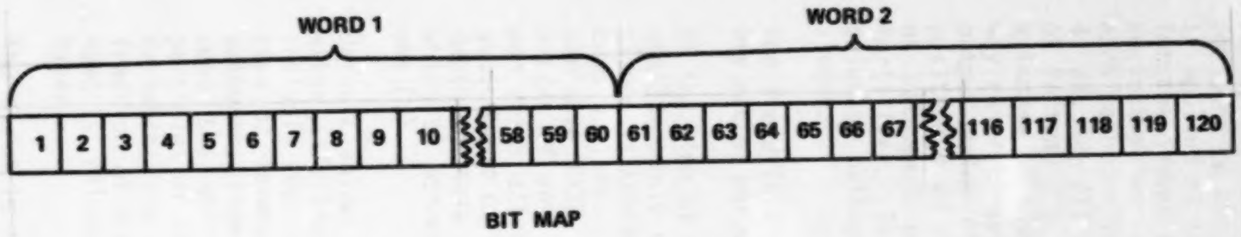
WORD 1
WORD 2
1
2
3
4
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8
9
10
58
59
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62
63
64
65
66
67
116
117
118
119
120
BIT MAP

BIT POSITION	KEYWORD	
1	EMPHASIS:	REVIEW
11	PATHOGENS:	BACTERIA
41	TREATMENT:	NONE
54	SLUDGUSE:	IRRIGATION
64	HAZARD:	VIRULENCE
68	TRANSPORT:	PERCOLATION
74	SOIL TRAIT:	PH
83-120	UNUSED	

Figure B-29. Bit map - keyword example.

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FORTRAN WRITE statement (i.e., output buffers are filled and then dumped only when a READ statement is encountered or overflow occurs) the interrupt messages are in SUBROUTINE IGTCHR rather than DPDRVR or LIDRVR. In effect, when the user sees the data being printed on the screen, the executed code is not in DPDRVR or LIDRVR where the WRITE statements are, but in IGTCHR where the READ statement is. The READ causes the output buffer to be flushed.

Program File Requirement

The PRINT and LIST commands write to TAPE2 which is a file called LPRNT. When execution of the Library Retrieval Program is completed, there will be a local file called LPRNT in the user's disk area. The user can then manipulate this file under NOS in any manner, such as dispatching it to the central site or printing it on the local terminal.

The retrieval program builds its MSIO indices from TAPE89 which is OLDLRF as created by the storage program. These master directories are written out to TAPE91 and TAPE92. TAPE5 and TAPE6 are respectively the input and output files for the terminal.

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9-1/8"
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